VOICE TECHNOLOGY

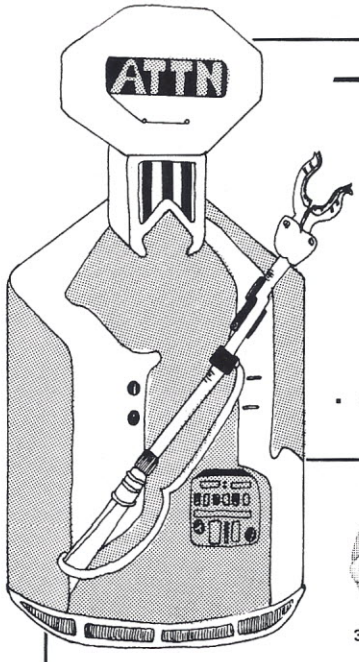
APRIL 1985 VOL. 7 NO. 4 $3.00 USA/$3.50 CANADA

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

INSIDE:

An Interview With Joseph Engelberger

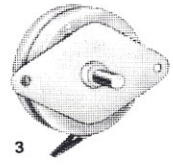


— ROBOTICS ENGINEERS —

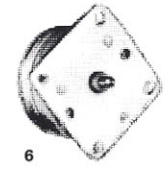
Are you interested in STEPPING MOTORS AND COMPONENTS at prices 50–70% OFF OEM for IMMEDIATE OFF–THE–SHELF DELIVERY in PROTOTYPE OR PRODUCTION QUANTITIES with our UNCONDITIONAL MONEY-BACK GUARANTEE?

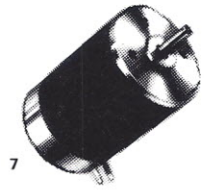
. . . then AMERICAN DESIGN COMPONENTS

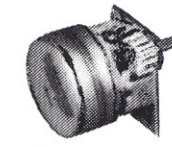
is your First Source!


3

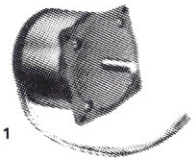
4

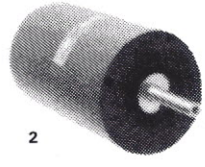

6


7


8

STEPPING MOTORS


1


2

Step Angle	Voltage DC	Stall Torque oz/in	Type	Dimensions 1) Body 2) Shaft	Fig.	Manufacturer & Part No.	Price Each	Price 2 For
1	5	17*	PM	1) 1.875 x 1.75 x 1.0 H 2) .5 x .125	8	N.A. Phillips A82310-M2	$ 9.95	$14.95
1.8	1.3	200	PM	1) 2)	2	Sigma 20-4247TD-200F1.3	34.50	59.50
1.8	1.8	150	PM 4 Ø	1) 2 3/16 L x 2 3/16 dia. 2) 3/8 dia. x 1 L	1	Superior Electric M091-FD-6009	34.50	59.50
1.8	1.8	72	PM 2 Ø	1) 2 3/16 L x 2 3/16 dia. 2) 1/4 dia. x 3/4 L	1	Superior Electric M061-FF-6201B	19.95	37.50
7.5	5	13	P M	1) 1 1/2 L x 2 1/8 dia. 2) 5/16 L x 1/4 dia.	6	Airpax A82816	8.95	16.95
7.5	9	36	P M	1) 1 3/4 L x 2 3/4 dia. 2) 1/4 dia. x 1/2 L	6	N.A. Phillips B82916	9.95	17.95
7.5	12	13	P M	1) 1 L x 2 1/4 dia. 2) 1/4 dia. x 3/4 L**	3	N.A. Phillips A82733M2-3	9.95	17.95
7.5	12	16	P M	1) 1.97 L x 1.39 W x .68 H 2) .375 x .125	4	Airpax K82201-P2	5.95	9.95
15	28		VR	1) 2) Size 15	7	Rapid Syn. 15R-01X	29.95	49.50
90	24		PM 4 Ø	1) 2) Size 15	7	Rapid Syn. 15P-03X	34.50	59.50

* Calculated ** Shaft with ½ diameter *** 8 threads/inch † w/worm drive

ROBOTICS KIT

A

(Springs, Belts, Pulleys, & Gears)

Consists of:
9 Timing Belts (7.5" to 13")
2 Round Belts (12" to 15")
15 Nylon & Plastic Spur & Drive Gears
22 Torsion Springs
6 Compression Pulleys
19 Tension Springs

All New **$19.95**

SWITCHING POWER SUPPLY

B

+24V @ 2.2 A
−12V @ 1.7 A
+5V @ 3 A
Dimensions: 7⅜" x 6⅛"
Input: 115/230 VAC; 50/60 Hz.

$19.95 New

0–200 RPM DC MOTOR

C

PM Type. 27.5 Volts @ 200 ma.
30 oz/in torque, reversible
Shaft: ¼" dia. w/9-tooth spline
Mfr. Pioneer Electric #48P20PA

$29.50 RFE

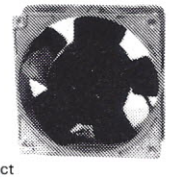
NICAD BATTERY & CHARGER

D

13.2 V @ 1.65 AH
Contains 11 C Cells.
Portable computer battery back-up.
Mfr. GE #41B035BB00101
with 17 Volt Battery Charger.

$29.95 (set) New

115 CFM MUFFIN FAN



Metal frame
with 5 high-impact
plastic blades. For
cooling Hi Fi, electronic & computer equipment. Mounts for intake or exhaust.

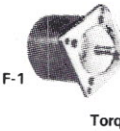
E-1 — **115 VAC/60 Hz.**
Mfr. Torin TA500PSC

$7.95 New

E-2 — **24 VDC/11 W**
Mfr. Centaur CNDC24K4-601

$14.95 RFE

72 RPM GEARLESS SLO-SYN SYNCHRONOUS STEPPING MOTORS


F-1

F-2

F-3

Part #	Torque (oz/in)	Fig.	Dimen. (L x D)	Shaft (L x D)	Price
SS-25	25	F1	2.27 x 2.24	.81 x .25	$10.00 New
SS-150	150	F2	4.74 x 4.23	1.25 x .375	12.00 RFE
SS-400	700	F3	6.99 x 4.23	1.38 x .375	25.00 RFE

115 VAC/60 Hz. Very rapid (start/stop) reversing characteristics.
Wiring diagram and appropriate capacitor supplied.
Mfr. Superior Electric

For all phone orders, call
TOLL-FREE
(800) 524–0809
In New Jersey, call
(201) 939–2710

American Design Components 62 Joseph St., Moonachie, NJ 07074 (201) 939–2710

Circle 2

Publisher
Chris Crocker

Editor
Carl T. Helmers, Jr.

Consulting Editors
Russ Adams
Roberta Toth

Editorial Assistant
Stephanie vL Henkel

Production/Design Director
Nancy Estle

Assistant Production Manager
Tobee Phipps

Circulation Manager
James E. Bingham

Circulation Assistant
Jo-Ann Howe

Dealer Accounts
Meredith Makela

Typography
Maryellen Kelly

Receptionist
Vi Despres

Advertising Manager
Donna Louzier

Advertising Coordinator
Cheryl Wilder

Advertising Sales

Jerry Merrifield
Robotics Age Inc.
174 Concord Street
Peterborough, NH 03458
603-924-7136

Member of
Business Publications Audit

BPA
SELECTED MARKET AUDIT DIVISION

ROBOTICS AGE—[ISSN 0197-1905] is published monthly by Robotics Age Inc., Strand Building, 174 Concord Street, Peterborough, NH 03458, phone (603) 924-7136. Address subscriptions, changes of address, USPC Form 3579, and fulfillment questions to *Robotics Age* Subscriptions, 174 Concord Street, Peterborough, NH 03458. Second class postage paid at Peterborough, NH and at additional mailing offices. **POSTMASTER:** Send address changes to ROBOTICS AGE, 174 Concord St., Peterborough, NH 03458.

Subscriptions are $24 for one year (12 issues), $45 for two years (24 issues), $63 for three years (36 issues) in the USA and its possessions. In Canada and Mexico, subscriptions are $28 for one year, $53 for two years, $75 for three years. For other countries, subscriptions are $32 for one year, surface delivery. Air delivery to selected areas at additional charges, rates upon request. Single copy price is $3 in the U.S., $3.50 in Canada and Mexico, $4 in Europe, and $4.50 elsewhere. Foreign subscriptions and single copy sales should be remitted in United States funds drawn on a U.S. bank.

Address all editorial correspondence to the Editor at *Robotics Age*, Strand Building, 174 Concord Street, Peterborough, NH 03458. Opinions expressed by the authors of articles are not necessarily those of *Robotics Age*. To aid in preparation of acceptable articles, an Authors' Guide is available upon request, if accompanied by a self-addressed 8½ by 11 inch envelope with first class postage for 3 ounces. Unacceptable manuscripts will be returned if accompanied by a self-addressed envelope with sufficient first class postage. Not responsible for lost manuscripts or photos.

Each separate contribution to this issue, and the issue as a collective work, is © 1985 Robotics Age Inc. All rights reserved. Copying done for other than personal or internal reference use without the permission of Robotics Age Inc. is prohibited. Requests for permission should be addressed in writing to *Robotics Age* Permissions, Strand Building, 174 Concord Street, Peterborough, NH 03458.

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

APRIL 1985 VOL. 7 NO. 4

EDITORIAL

2 Research, Development, and Application — by Carl Helmers

FEATURES

11 Speech Recognition: Machines That Listen — by Dr. Thomas B. Schalk
The high cost of speech input and the overall performance shortcomings of speech recognition systems have prevented the development of a potentially strong market. The capabilities and limitations of today's speech recognizers are explored.

15 Joseph Engelberger: The Father of Industrial Robots Reflects on His Progeny — by Alfred B. Bortz
In an interview, Joseph Engelberger describes the development of the first industrial robot and reflects on the future of robot technology.

23 The Listeners: Intelligent Machines with Voice Technology — by Patricia S. Restaino and Richard M. Melnicoff
Toward a more human man/machine interface.

25 Forth for Computer Vision In Industrial Applications — by John E. Lecky
This article discusses the FORTH programming language as a development tool and operating system for industrial vision equipment. The constraints imposed by the industrial realities are covered, followed by a discussion of the features of FORTH which make it particularly well-suited to vision software.

29 A Second-Generation Autonomous Sentry Robot — by H. R. Everett
An autonomous sentry robot is described that involves an extensive control hierarchy and several different types of sensors for environmental interaction.

DEPARTMENTS

3 Calendar
6 In the Robotics Age
27 Advertiser Index
33 New Products
35 Classified Advertising

About the cover: This month's cover, supplied by VOTAN, represents a comparison of two speech patterns, one on the X and the other on the Y axis. Valleys indicate matching signals at a particular point while peaks are formed by differences. See the related article, "The Listeners: Intelligent Machines with Voice Technology," by Restaino and Melnicoff.

Editorial

Research, Development, and Application

BY CARL HELMERS

Robotics, as a technology, is still in its infancy. We can make precise mechanisms. We can control these mechanisms reliably with computers. We can even make intricate patterns of movement and operation using our computers. We can perform a large number of the detailed functions of robotics well. But ask a computer/robot to analyze a visual scene in order to take action with even a small amount of unplanned context; our technology is not yet up to the task. Just tally the number of engineering hours spent perfecting a myriad of special-purpose adaptations of "standard" robot arm end effectors. Joseph Engelberger, father of the modern industrial robot, captures the essence of current limitations in his remarks printed elsewhere in this issue.

The technology of today works; the technology of tomorrow will work better. Each new application of intelligent machine technology is an incremental improvement of previous work. A more capable vision system is installed with automatic feedback to other components of a system. More advanced communications abilities are added to better integrate a work cell into a factory data monitoring network. An autonomous vehicle materials transport system is freed of the need for dedicated hardware paths, allowing software changes to respond to the changing application needs. Computer aids to production tooling and setup become a way of life. Such changes and more are vital parts of an evolving technology. They do not come without engineering effort and general advances in knowledge of intelligent machine methodologies. What is needed to sustain progress and improvement?

PROMOTING INNOVATION

The robotics field, like all high-technology fields, needs innovation. Research and development activities, whether undertaken by companies, academic institutions, or government agencies, provide a reservoir from which innovation can be drawn. The value of such research and development to high-technology businesses is an obvious fact of life. New products and new methods of operation result. Research into means of improving productivity by applying principles of automated manufacturing—i.e. robotics—is one way of making older technologies competitive again. No improvement or innovation is possible without experimentation and promotion of new, untried methodologies.

The research and development budgets of any firm are sometimes the hardest to justify. The industrial thinkers and experimentalists are charged with the broadest of instructions from management: explore; gain new knowledge of our products and their users; experiment with new ways of doing things; characterize our materials and processes with a greater degree of precision; analyze our competitors' products. Research and development in automation of manufacturing is a necessary part of every manufacturing company's need to remain competitive and profitable. Robotics and automation research are integral to modern product design for manufacturability. The principle of serendipity in research applies; from such broad instructions, engineering researchers will find the unpredictable innovations and improvements needed to make an enterprise healthy and growing. With good internal communications about the results of research, the promising results can be cultivated and applied directly to a company's line operations.

AN EXAMPLE OF MANUFACTURING RESEARCH

We recently got a glimpse of a large company's implementation of manufacturing automation research and development activities. We attended the opening of an industrial laboratory dedicated to computer-integrated manufacturing applications research and development, the CIMLAB 1 facility of Digital Equipment Corporation in Shrewsbury, Massachusetts. The CIMLAB facility's host plant manufactures mass storage devices for computer systems. According to DEC, the goals of the CIMLAB facility are internal as well as customer-oriented. Experiments at the laboratory will extend the practical limits of techniques necessary for DEC to take advantage of computer-integrated manufacturing for its own manufacturing automation needs. The CIMLAB facility's ability to explore and demonstrate engineering concepts translates directly into advantages for Digital's manufacturing endeavors.

One characteristic demonstration provided during the opening-day tours presented the necessary steps from concept to prototype production of a base plate used in a new disk backup tape drive. To illustrate, the process of computer-aided design, design verification, prototype manufacture, and then final manufacturing method evaluation were shown. The design was passed over an Ethernet high-speed data communications link from one VAX computer graphic work station to another. Later, the design was used to control a Bridgeport milling machine with tool change capability. A set of engineering drawings was also emitted by a plotter. At each stage, the design was manipulated and improved before being handed off to the next stage. We were told that the final production versions of the part would be fabricated using the design data developed in the laboratory.

Digital is one of the largest suppliers of computers, software, and communications equipment necessary for computer-integrated manufacturing. So there is also the explicit marketing motive of using CIMLAB to help serve customer needs. The expertise and knowledge gained from internal use will be made available to DEC's manufacturing customers. Because DEC is in the computer business, and because a major market of their products is manufacturing customers, these computer-integrated manufacturing research activities have a direct, serendipitous, side effect.

AND THE PROCESS CONTINUES...

Research and development activities are a crucial part of the ongoing process of technology. All companies engaged in applications of intelligent machines must do research and development in areas such as conventional industrial robotics, light industrial robotics, flexible manufacturing, commercial automation, or even such unconventional areas as autonomous military, undersea, and personal robotic vehicles. The uses are complex, new, and in most cases relatively untried.

There are many details of intelligent machine applications where discovery, innovation, and development are needed. Advances are needed in hands-free voice interaction with human operators, in intelligent vision systems and their use to control actions, in the real-time control languages and operating systems appropriate for dedicated robotic control, in the development of educational materials for the technical people involved in robotics, in the communications techniques appropriate for multiple computer systems, in the mathematical basis for computation as used in robotic applications, and in the computer-aided design/engineering methods which support the modern robotics endeavor. This list cannot conceivably exhaust the potentially fruitful areas for further research and development. ■

Calendar

APRIL

9–11 April. Hartford Tool & Manufacturing Engineering Conference & Exposition. Sheraton Hartford Hotel, Hartford, CT. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

The conference, sponsored by the Society of Manufacturing Engineers, will feature 18 all-day workshops and four half-day technical sessions on such topics as computer-aided design and analysis, geometric dimensioning and tolerancing, industrial paints and painting methods, electrochemical machining, and group technology and computer-integrated manufacturing. The accompanying exposition will feature a machine tool area arranged by the American Machine Tool Distributors' Association.

17–24 April. Hannover Fair. Hannover, West Germany. Contact: Delia Associates, PO Box 338, Whitehouse, NJ 08888, telephone (201) 534-9044.

The 1985 Hannover Fair will place special emphasis on mechanical and fluid power transmission, controls, and industrial parts handling. A separate sector of the fair has been set up to accommodate pertinent exhibits.

19 April. Developments in Japanese Robots. Montclair State College, Upper Montclair, NJ. Contact: Prof. Gideon Nettler, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4294.

This talk, conducted by Mark Llangenfelld, Hitachi America, Ltd., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

22–25 April. LASERBOTICS: Combining Laser and Robot Technologies. Ann Arbor, MI. Contact: Steve Palma, SME Special Programs Department, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

The program will feature speakers from the U.S., Europe, and Asia and will examine the latest advancements in the science of combining lasers and robots to improve productivity. Co-chairpersons Jack Lane, director of the Robotics Center at the GMI Engineering and Management Institute, and David Belforte, president, Belforte Associates, are preparing an agenda covering the latest advancements in laser tooling, robotic part presentation, laser-guided robotics, fiber optics, and laser/robot welding and inspection.

23–24 April. 1985 Conference on Intelligent Systems and Machines. Oakland University, Rochester, MI. Contact: Professor Nan K. Loh, Conference Chairman, Center for Robotics and Advanced Automation, School of Engineering and Computer Science, Oakland University, Rochester, MI 48063.

Papers to be presented at the conference will reflect both advances and applications in all aspects of intelligent systems and machines. Topics will include intelligent robots, machine intelligence, adaptive control and estimation, visual perception, artificial intelligence for engineering design, intelligent simulation tools, computer-integrated manufacturing systems, knowledge representation, expert systems, game theory and military strategy, interpretation of multisensor information, and automatic programming.

28–30 April. Intelligent Vision Systems. Holiday Inn, Monterey, CA. Contact: Richard D. Murray, Director of Conferences, Institute for Graphic Communication, Inc., 375 Commonwealth Ave., Boston, MA 02115, telephone (617) 267-9425.

This conference is based on the premise that intelligent vision systems have been shown to be a vital part of the factory automation concept, and that they will play an important role in robot guidance and control, enabling robots to perform many more complicated functions than they have heretofore. The goal of the conference is to contribute to the industrial educational process by addressing both technical and marketing aspects of intelligent vision.

30 April, 1–2 May. Artificial Intelligence and Advanced Computer Technology Conference/Exhibition. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Company, 331 West Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

The direction of AI '85 is commercial, and technical sessions will include such topics as AI in office automation, natural language interfaces, AI in defense systems, computer vision, and the legal and social implications of artificial intelligence.

ROBOTICS CATALOG

TOUCH·PAINT® PRESSURE SENSITIVE MATERIAL

A FEW DROPS OF THIS UNUSUAL MATERIAL WILL MAKE A LOAD CELL THAT CHANGES RESISTANCE IN PROPORTION TO APPLIED PRESSURE- GIVING YOUR ROBOT A SENSE OF TOUCH WITH NO MOVING PARTS!

CELLS CAN BE OF SIMPLE CONSTRUCTION- JUST TWO CONTACT SURFACES, WITH TOUCH-PAINT BETWEEN THEM. WITH THE APPROPRIATE INTERFACE & CONTROL, YOUR ROBOT HAND CAN EXERT AN EXACT, CONTROLLED FORCE ON DELICATE OBJECTS!

DESIGNERS' KIT $20

INCLUDES 2 OZ TOUCH-PAINT, SAMPLE CELL, PROJECT GUIDE

WIRELESS VIDEO LINK

SEND VIDEO AND AUDIO SIGNALS FROM YOUR ROBOT CAMERA, VCR, OR OTHER SOURCE TO A REMOTE MONITOR, HOST COMPUTER, ETC. RF SYSTEMS TO 75' RANGE / INFRA-RED SYSTEMS TO ONE MILE

SYSTEMS FROM $99

DUAL STEPPER DRIVE BOARD $50

PLUGS INTO VIC-20 OR C-64 PORT - 60V, 8A

) HERO JR. $799 (

YUASA RECHARGEABLE BATTERIES -- 40% OFF LIST!
STEPPER MOTORS-BOOKS-KITS-PARTS-MORE!

CALL OR WRITE FOR CATALOG!

SKYE 537-F OLATHE AURORA, CO 80011 (303) 361-9259

Circle 21

Calendar

MAY

8 May. Simple Solutions to Complex Robot Applications. Montclair State College, Upper Montclair, NJ. Contact: Prof. Gideon Nettler, Department of Mathematics & Computer Science, Montclair State College, Upper Montclair, NJ 07043, telephone (201) 893-4294.

This talk, conducted by Michael T. McCraley, Panasonic Industrial Co., is part of the Montclair State College Department of Mathematics & Science robotics lecture series.

14–16 May. 1985 Test & Measurement World Expo. San Jose Convention Center, San Jose, CA. Contact: Meg Bowen, Conference Director, Test & Measurement World Expo, 215 Brighton Ave., Boston, MA 02134, telephone (617) 254-1445.

The 24 conference sessions will feature more than 100 technical papers on topics such as testing of surface-mounted devices, electro-optics test/optical metrology, process monitoring, the ergonomics and psychology of factory automation, machine vision, and communications and microwave testing. There will also be product demonstrations and a large exhibit.

15–21 May. JAPANMEC '85. Osaka, Japan. Contact: Michael Solomon, Michael Solomon Associates, 509 Madison Ave., Suite 1708, New York, NY 10022, telephone (212) 223-3340.

The Japan International Measuring and Control and Industry Show '85 will be one of the opening events at the the New Osaka International Fairgrounds. Twelve categories of instruments will be on display: precision measuring, metering, optical measuring, electric/electronic measuring, testing, analytical, control, information-transmission, peripheral devices/auxiliary equipment, and other related equipment. Concurrent and at the same location will be FACTRO '85, a new international show devoted to flexible manufacturing systems.

20–22 May. Commercial Artificial Intelligence: Myths & Realities. Century Plaza Hotel, Los Angeles, CA. Contact: Lynn M. Bentley, Marketing Manager, Gartner Group, Inc., 72 Cummings Point Rd., PO Box 10212, Stamford, CT 06904, telephone (203) 964-0096.

The emphasis of this conference will be real-world applications of artificial intelligence in large corporations and the structure of the emerging AI industry. Topics to be covered include AI in computer operations, manufacturing, financial services, and office information systems; AI-based user interfaces; and AI and personal computers.

JUNE

3–5 June. 1985 Eastern Design Engineering Show and ASME Conference. Bayside Exposition Center, Boston, MA. Contact: Show Manager, Eastern Design Engineering Show, Cahners Exposition Group, 999 Summer St., Stamford, CT 06905, telephone (203) 964-8287.

Conference organizers describe the conference as "The first such East Coast event since such new technologies as CAD/CAM and composite materials have revolutionized the design engineering field." An outgrowth of the 32-year-old national show, the conference will have the same goals: the design of new products and the re-design of conventional products with concentration on improving the productivity of design engineers.

The design engineering division of the American Society of Mechanical Engineers will sponsor a program covering areas that have developed as the result of advances in computer technology, such as CAD/CAM, finite element analysis, composite materials development, and artificial intelligence and expert systems.

3–6 June. Robots 9. Cobo Hall, Detroit, MI. Contact: RI/SME Public Relations, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

Almost everything that can be said and seen on the subject of robots will be offered at Robots 9 when 80 or more robotics experts discuss new breakthroughs in systems software, remote applications, vision, intelligent controls, management perspectives, and R&D. Other sessions will consider new developments in mechanical and electronic assembly, robot programming languages, safety, aerospace applications, human productivity implications, robot design, and justification and decision-making.

In addition, there will be an exhibition of more than 250 robots and robotic systems demonstrating welding cells, laser processing, water jet cutting, material handling, assembly, gantry applications, and other manufacturing operations. Many of the systems will be equipped with the latest vision and tactile sensors, new controls and positioning devices, and end effectors and tooling.

6–7 June. Workshop on Robot Standards. Ponchartrain Hotel, Detroit, MI. Contact: Leonard Haynes, A123 Metrology Building, NBS, Gaithersburg, MD 20899, telephone (301) 921-2181.

The National Bureau of Standards and the Navy's Computer-Integrated Manufacturing Technology Program will sponsor a workshop on robot standards in conjunction with the Robots 9 conference. Planned topics include control system interfaces to robots, sensors, databases, and high-level control systems; mechanical interfaces to grippers and other end effectors; programming languages and environments; measures of performance; and human interfaces.

The workshop is co-sponsored by the Robotic Industries Association, the American Society for Testing and Materials, the Institute for Electrical and Electronic Engineers, the American National Standards Institute, and the Electronic Industries Association.

10–14 June. Robot Manipulators, Computer Vision, and Intelligent Robot Systems. The University of Stirling, Stirling, Scotland. Contact: Director of the Summer Session, M.I.T., Room E19-356, Cambridge, MA. 02139, telephone (617) 253-2101.

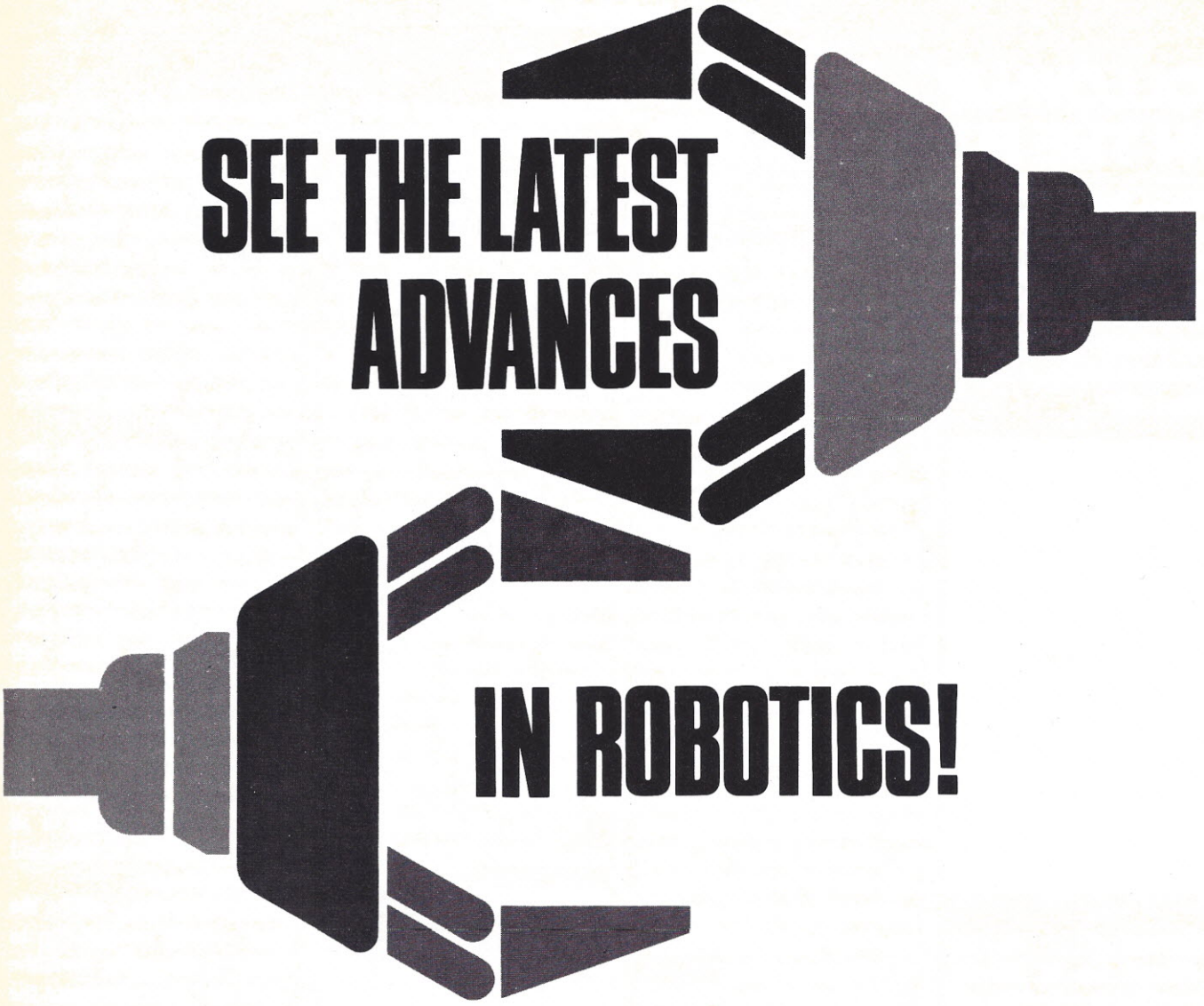
The aim of this course will be to prepare the participant for the sophisticated methods soon to be employed in advanced automation. Emphasis will be placed on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation. The use of existing industrial robots and binary vision systems will be covered also.

18–20 June. Canadian Robotics Show. International Centre of Commerce, Toronto, Canada. Contact: Ron McCreary, Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800, or Hugh F. Macgregor & Associates, 360 Consumers Rd., Willowdale, Ontario, Canada M2J 1P8, telephone (416) 491-9656.

This new event is a response to the Canadians' rising interest in robotics, which is creating new marketing opportunities for U.S. robot suppliers, according to an RIA spokesman. Running concurrently will be the fourth annual Canadian CAD/CAM show. Also, some of the exhibitors from the Robots 9 show are expected to display their products at the Canadian Robotics Show.

24–27 June. Fourth International Symposium on Unmanned Untethered Submersible Technology. University of New Hampshire, Durham, NH. Contact: Carol Bryant, University of New Hampshire, Marine Systems Engineering Laboratory, PO Box G, Durham, NH 03824, telephone (603) 749-6056.

This symposium will cover subjects such as acoustics/communications, imaging, control dynamics, artificial intelligence, data sources/sinks, and knowledge-based guidance. The emphasis will be on stimulating informal interaction among the participants. A one-day classified session is also planned.



SEE THE LATEST ADVANCES IN ROBOTICS!

ROBOTS 9

JUNE 3-6, 1985 · COBO HALL · DETROIT, MICHIGAN

Discover how robots can make your company more productive and profitable! Register now for ROBOTS 9, the world's premier robotics show and conference. More than 250 robots will be in action at the show demonstrating the latest advances in robotics. Real-world applications for assembly, welding, material handling, finishing and machine loading are just a few of the manufacturing processes to be examined.

At the conference you'll learn new ideas from international experts in problem-solving technology and applications, systems, safety, research & development, education and training, management perspectives and more!

CALL TODAY FOR COMPLETE ROBOTS 9 DETAILS... 313/271-0777

Exposition sponsored by Robotic Industries Association

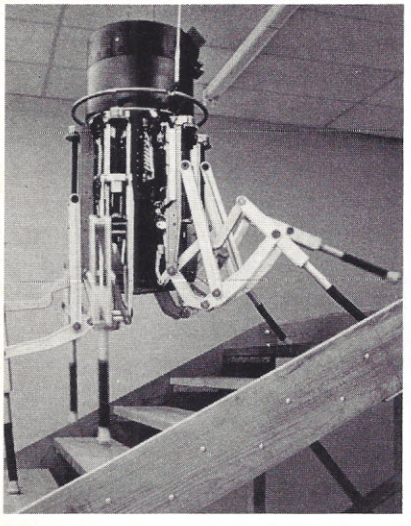
Conference sponsored by Robotics International of the Society of Manufacturing Engineers

Circle 20

Edited by Stephanie vL Henkel

FOLLOW-UP ON THE FUNCTIONOID

ODEX I, the six-legged robot you met in the September/October '83 issue of *Robotics Age*, is back with smooth new moves that have brought his proud parents, Odetics Incorporated of Anaheim, a wave of contract offers.



Weighing only 370 lbs., this functionoid can lift 450 lbs. with one leg, or articulator, and carry the load around. He can clean and jerk 600 lbs. per limb. And with a special lifting bracket attached to his payload area he can hoist—ready for this?—2100 lbs., 5.6 times his own weight.

ODEX can be tall (78 in.), short (36 in.), wide (105 in.), or skinny (21 in.). He can change shape while walking along. Advancing three legs at a time, and whirring like an electric can opener, he can climb and descend a 33-inch stair riser (more than a giant step for a man but manageable for a functionoid). And as for his diet, it's 2 watts when he's looking for something to do and 350 watts when he's busy—less than it takes to brighten a backyard picnic.

ODEX was built purely as a research vehicle, created without predefined applications or customer requirements. His engineers were motivated by the challenge of the project and proceeded on the premise that a walker could outperform a roller in a variety of roles.

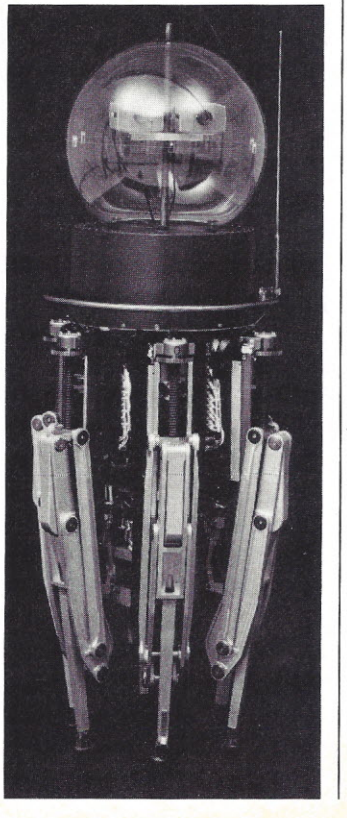
First to come courting was the RCA Government Systems Division with a proposal to share technology. The plan calls for work on a mobile robotic system for the U.S. Department of Defense, with Odetics developing the transport mechanisms and RCA responsible for artificial intelligence and the payload modules. The result of this association is expected to be a mobile robot for sentry duty and for hazardous assignments such as land mine disposal and exploration of hostile or inaccessible areas.

The Electric Power Research Institute also is looking for a brave robot to send into the "hot" areas of nuclear power plants. A study carried out for EPRI suggested that a legged functionoid like the agile and omnidirectional ODEX might be just the ticket to handle a power plant's cluttered environment. Of course, ODEX's great strength and his imperviousness to radiation poisoning will come in handy too.

ODEX's high payload-to-weight ratio impressed the Army enough for them to give Odetics a contract to develop a manipulator arm for materials handling. The prototype will weigh less than 500 pounds and be able to lift and manipulate a 500-pound payload up to 15 ft. away. The final version, to be mounted on a rolling platform, is expected to have a 25-foot reach and a 4000-pound payload capability.

The teleoperation principles devised for ODEX will be put to use by the Navy as a means of dealing with a particularly horrendous problem—fire aboard an aircraft carrier. On the flight deck, closely parked planes full of jet fuel can explode like bombs, scattering burning debris and live ordnance. Odetics is thinking of a teleoperated firefighting system that will be small, simple, wheeled, maneuverable, and able to withstand heat and fire. Its function will be to get a hose to the fire quickly and position the nozzle according to the teleoperator's commands.

Next to ask for an ODEX spinoff was the U.S. Department of Agriculture, which was interested in a high strength-to-weight manipulator, or arm, with precisely-controlled high-speed performance. Its purpose: to pick oranges. The new technology that can combine image recognition, robotic arms, mobility, and artificial intelligence promises to automate harvesting without damage to either trees or fruit.



Not to be outdone, the Department of Energy has contracted with Odetics to develop a walking robotic test vehicle to use in the D.O.E.'s nuclear reactor facilities. ODEX's cousin, the SRL (Savannah River Laboratory) Walking Robot, will have a jointed arm, a TV camera system, a microprocessor-based control system with firmware containing all control algorithms, an operator's console for remote control of all functions of the system, and electrical power.

The manipulator will be the most striking modification to ODEX I. Operating from the top of the primary structure, the unit will consist of a jointed arm on a rotating turret. At the wrist will be a parallel tong gripper and a TV camera/lighting system. The arm's reach will include the full circumference of the robot from the floor to seven feet in the air. The camera will send black-and-white two-dimensional images to the teleoperator through a monitor on the control console.

So, whether they're fighting fires, picking fruit, or asking "Who goes there?", ODEX I and his kin are testifying to the merits of pure research and ingenuity for its own sake. Sometimes you find out where you're going only when you get there. ■

In The Robotics Age

PEOPLE

►**Lynn Hennessey**, formerly of Hamilton Test Systems (a division of United Technologies Corp.) has joined **Cognex Corporation** as public relations specialist. Prior to working at Hamilton, she coordinated communications for a $2-billion joint venture energy project cosponsored by EG&G. Cognex, headquartered in Needham, MA, designs, manufactures, and markets vision systems for automation and quality control.

►**Pacific Scientific Motor & Control Division** has named **David J. Koerber** manager of military programs. Koerber's previous experience was as a project engineer with the Sundstrand Corp. and Lockheed Aircraft. The Motor & Control Division is based in Rockford, IL. Pacific Scientific, a NYSE company, is in Anaheim, CA.

►**Paul Cipriani** is a new project engineer in the R&D Department of **Automated Assemblies Corp.** of Clinton, MA. AAC is the North American distributor of Sailor robots and Seiko robots, and a Value Added Remarketer for IBM robots. Before joining AAC, Cipriani was affiliated with Sanders Associates and later was an engineering intern with his new employers.

►**William H. Southworth** and **Dr. Barry Unger** have joined the board of directors of **Datacube, Inc.** as advisors in strategy, finance, and operations management. Unger was a cofounder and executive vice president at Kurzweil Computer Products, Inc. He has also held university and presidential appointments. Southworth is a director and past president of CADMUS, Inc. His former positions were with the Pixel Division of Instrumentation Laboratory, Inc., Infoton, Beehive International, Digital Equipment Corp., Data General Corp., and MIT's Project MAC. Datacube, in Peabody, MA, specializes in the acquisition, processing, and display of images for applications including factory automation, medical diagnostics, and broadcast equipment. ■

EDUCATION

Statewide CAD

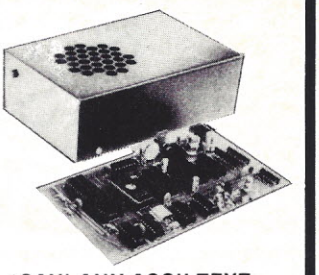
West Virginia has become the first state in the country to adopt a statewide plan for CAD instruction. State officials have announced the purchase of 495 AutoCAD programs from Autodesk, Inc. that will eventually be installed in 125 occupational and vocational learning centers. Funding for the purchase, part of West Virginia's Microcomputer Educational Network program, was shared by state appropriations, an Appalachian regional grant, and by the Job Training Partnership Act—federal programs designed to stimulate new job opportunities in geographic areas of high unemployment.

Robotics Vision Grant

The **University of New Hampshire** has received a $20,000 grant from **Davidson Rubber Co.** of Farmington, NH. The money, an unrestricted gift earmarked for robotics vision research, will be used to buy various supplies and equip-

SPEECH SYNTHESIZER

THE Big Mouth



LISTEN! Your HERO or other robot, or your computer could be talking to you through the BIG MOUTH. *The first affordable True Speech Synthesizer* can be talked to through it's parallel or serial printer port or be connected to your robot's bus.

APPLICATIONS:
- Robotics
- Automatic Testing
- No Software Required
- Will run on any computer

IT WILL 'SAY' ANY ASCII TEXT
- Handicapped Aid
- Games
- 1000 Character Buffer

- Embed phonemes in text for those special words.
- Programmable: Vocal-Tract frequency, inflection rate, duration pitch, articulation amplitude...for all 64 phonemes.
- Can be programmed to make sound effects or sing!

Complete **$249** Add $5 S&H

KITS
- PCB & Eprom + inst. $74 + $3 S&H
- PCB kit + inst. $161 + $5 S&H
- Complete kit $199 + $5 S&H

Calif. Res. add 6% tax

Phone Orders or Demonstration
(714) 734-6006

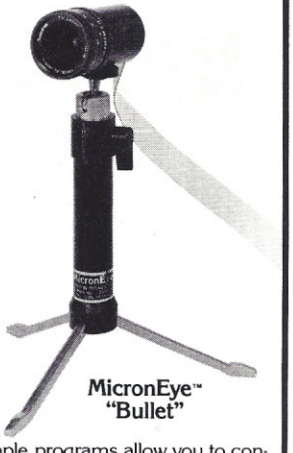
Dealer Inquiries Invited

AstroTronics MICROSYSTEMS
1137 Topaz Street
Corona, CA 91720

Circle 15

Now Your Computer Can See!
$295.00*

A total imaging system complete and ready for plug-and-go operation with your personal computer.



MicronEye™ "Bullet"

The MicronEye™ offers selectable resolution modes of 256 x 128 and 128 x 64 with operating speeds up to 15 FPS. An electronic shutter is easily controlled by software or manual functions, and the included sample programs allow you to continuously scan, freeze frame, frame store, frame compare, print and produce pictures in shades of grey from the moment you begin operation.

Only the MicronEye™ uses the revolutionary IS32 OpticRAM™ image sensor for automatic solid state image digitizing, with capability for grey-tone imaging through multiple scans. And with these features, the MicronEye™ is perfectly suited for graphics input, robotics, text and pattern recognition, security, digitizing, automated process control and many other applications.

The MicronEye™ is available with immediate delivery for these computers: Apple II, IBM PC, Commodore 64 and the TRS-80CC (trademarks of Apple Computer Inc., International Business Machines, Commodore Corp., and Tandy Corp. respectively).

Phone for MicronEye™ information on the Macintosh, TI PC and RS232 (trademarks of Apple Computer Inc. and Texas Instruments respectively.)

*(Add $10.00 for shipping and handling [Federal Express Standard Air]; residents of the following states *must add sales tax*: AK, AZ, CA, CO, CT, FL, GA, IA, ID, IL, IN, LA, MA, MD, ME, MI, MN, NC, NE, NJ, NY, OH, PA, SC, TN, TX, UT, VA, VT, WA, WI.)

MICRON TECHNOLOGY, INC.
SYSTEMS GROUP
1475 Tyrell Lane
Boise, Idaho 83706
(208) 386-3800
TWX 910-970-5973

Journal of ROBOTIC SYSTEMS

EDITORS: Gerardo Beni and Susan Hackwood
University of California, Santa Barbara

An international journal presenting high-level scholarly discussions and case studies on automation, taskware design and implementation of robot systems. Articles deal with a broad range of new robotic and mechatronic applications, especially high-technology systems applications requiring a novel approach to task structuring. Topics covered include hardware, programming, tasks, machine perception, controls, and peripherals technology. Special features include editorial commentary, Japanese language abstracts, and brief communications about the field.

For roboticists in academia, industry, and government who develop, design, install, and perfect functioning robot systems.

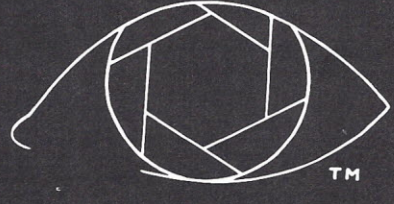
Volume 2, 1985 Quarterly $95 per year

To subscribe, write to: Subscription Department-5-6020, John Wiley & Sons, 605 Third Avenue, New York, NY 10158...or call TOLL FREE 1-800-526-5368. In New Jersey, call collect (201) 342-6707.

John Wiley & Sons

MACHINE VISION

FOR THE IBM PC



VOLKSVISION™: A COMPLETE SYSTEM FOR UNDER $1000!
INCLUDES DIGITIZER, CAMERA, UTILITY SOFTWARE AND CABLES.

For more information, send the coupon below or circle the reader service number.

ForSight, Inc., 21 Elm St., Wakefield, MA 01880

IBM AND IBM PC ARE TRADEMARKS OF IBM CORP

I wish to receive more information about **VOLKSVISION™**

The monitor driver board on my computer is:

☐ IBM Color ☐ IBM Monochrome ☐ Tecmar ☐ Hercules
☐ Other _____

NAME _____

STREET _____

CITY, STATE, ZIP _____

Send To: ForSight, Inc., 21 Elm St., Wakefield, MA 01880

In The Robotics Age

ment for the robotics lab jointly sponsored by the university and Davidson. Officials of both said the program would be of mutual benefit—students will use the lab and Davidson will use the students' achievements in robotics vision. Davidson, a subsidiary of Ex-Cell-O Corp., has given the university a previous grant and a robot.

Professional Development Center

The Society of Manufacturing Engineers has opened a Center for Professional Development at its Dearborn, MI world headquarters. Designed primarily to train manufacturing management, the center will offer a variety of both specific and overview courses in computer-integrated manufacturing. Instruction will include demonstrations, simulations, field trips, video learning, and hands-on experience with computer hardware and software. IBM microcomputers will be used for the three- and five-day courses.

SME President Forrest D. Brummet described the center as "an effective way to update and retrain America's manufacturing managers. As our industries integrate more advanced technologies—machine vision, robotics, flexible manufacturing systems—mid-managers and above need to acquire the skills to apply these technologies effectively." Twenty-three courses have been scheduled for the year. General information is available at (313) 271-1500, ext. 341. For registration, call (313) 271-0039.

Robotics Welding Training

Anticipating a future when, in welding, the one who knows how will work for the one who knows why, **Northern Illinois University** in De Kalb has opened a robotics center to prepare its engineering students to work with a rapidly growing robotics welding industry. Roy Hulfachor, NIU associate professor of industry and technology, predicts that by 1988 welding will account for a third of the country's industrial robotics applications. Students at the new center will be learning on a Unimate computerized, reprogrammable welding robotic work cell. Smaller robots with vision will be used for study in research and design. ■

CORPORATE NEWS

►The Robotics/Automation Division of **Seiko Instruments U.S.A.** has moved into an expanded facility. The new offices, at the company's Torrance, CA, headquarters, house customer training classrooms, a new computer system, and space for a larger sales staff.

►**Westinghouse Electric Corp.** has purchased a 38 percent equity interest in **Perceptrics Corp.**, a Knoxville, TN-based company that develops and manufactures sophisticated image-processing equipment.

►The Buick City division of **General Motors** in Flint, MI, has arranged to purchase two Associative Pattern Processors from **Pattern Processing Technologies, Inc.** of Minneapolis, MN. Mounted in GCA robots, the vision systems will be used as part of a robotic

In The Robotics Age

unloading system for engines and transmissions.

►**Manufacturing Data Exchange** of Minneapolis, MN, (MDX) and **Metcut Research Associates** of Cincinnati, OH, have signed an agreement whereby CUTDATA, Metcut's computerized version of their Machining Data Handbook, will be available through MDX as a complementary product to MDX's Factory Automation Software.

►**American Robot Corp.** has formed a wholly owned subsidiary, American Industrial Vision Corp., to develop advanced vision products and applications technology for automotive and electronic applications over the next two years. The company has received $5.6 million in equity and research and development funding from **BMW,** the Munich, Germany-based vehicle manufacturer, to support the development of this vision technology. Systems will be developed for inspecting complex assemblies, dimensional gauging, seam location and tracking, and adaptive robot control.

►The machine vision market has gained another member with the formation of **Videk**, a wholly owned subsidiary of the **Eastman Kodak Co.** Videk will develop, manufacture, and market intelligent vision systems for use in factory automation and computer-integrated manufacturing applications. The new company will initially offer systems for industrial measurement and surface flaw analysis applications in both turnkey packages and custom-engineered systems.

►**Symbolics, Inc.** of Cambridge, MA, is off for Japan and the Tsukuba Expo '85 World's Fair. The United States pavilion there is dedicated to artificial intelligence, and in it Symbolics will exhibit advanced symbolic computers diagnosing electronic equipment, doing integral calculus, performing Bach preludes, and playing the Japanese game *Go*.

►**GMF Robotics Corp.** of Troy, MI, and **Meta Machines, Ltd.** of Oxford, England, have entered into an exclusive agreement covering distribution and a joint development program for the British company's MetaTorch, a laser-based vision system designed specifically for arc welding applications. GMF will be the only robot vendor in the U.S. with a direct link to Meta Machines for interfacing the MetaTorch. ■

MARKET RESEARCH

According to a new market study published by **Venture Development Corp.**, the pharmaceutical industry will be the third largest market for batch control systems by 1990, coming in behind the chemical and the food and beverage industries. Venture predicts that batch processing will grow by an annual 20.9 percent, more than tripling by the end of the decade. Contributing to this rapid increase are advances in control systems, specifically regulatory control and process graphics capabilities in programmable controller-based systems. The market share for batch systems in the metals and the pulp and paper industries is expected to decline some-

PERSONAL ROBOTICS EXCLUSIVELY
FACTORY AUTHORIZED DEALERS

BURN YOUR OWN RB5X PROMS
Introducing our Tiny BASIC PROM Development System
Hardware, Software, Documentation — Complete Package for 8073 CPU
VIC-20 Version ..... $299.95 Commodore 64 Version $349.95
Dealer Inquiries Invited

CUSTOMER SERVICE POLICY
1. No dissatisfied customers.
2. Call if you have questions—we know our products.
3. Unlimited help when you need it.

KITS	List	SALE
MOVIT		
Screwdriver Kits—No Solder—FUN		
Avoider	44.95	40.15
Circular	67.95	63.75
Line Tracer	39.95	36.75
Medusa	27.95	26.25
Memoconcrawler	74.95	70.15
Monkey	24.95	23.65
Mr. Bootsman	30.95	29.25
Peppy	24.95	23.65
Piper Mouse	44.95	40.13
Sound Skipper	24.95	23.65
Turn Backer	39.95	36.75
We have sold hundreds of these items. They work as they should and they last.		
HARVARD ASSOC.		
Turtle Tot	299.00	275.00
Excellent for simple educational applications. Our customers have been very satisfied.		
ROBOT SHOP		
Robot Bug	129.95	122.00
Z-1	149.95	136.50
Z-2	249.95	223.50
Simple and dumb, but lots of potential for customizing and expansion.		

ROBOTS	List	SALE
ANDROBOT		
Slave to your computer		
TOPO III	1595.00	1485.00
Accessories		CALL
TOPO III moves and talks very well. It uses LOGO-like commands and a good text-to-speech system.		
RB ROBOT		
Download from your computer		
RB5X	2295.00	2058.00
Accessories		CALL
Program it in Tiny BASIC or use a SAVVY to Tiny BASIC "compiler". RB5X has bumpers and sonar; voice with sound effects, arm, easy-to-use programming language, additional senses are available. It is good quality. Our two demos have seen hard use and haven't broken down yet!		
ARCTEC		
GEMINI—price not announced		
What we have heard about GEMINI has us very excited, but we can't talk about it yet. If you're interested, let us know and we'll keep you posted.		

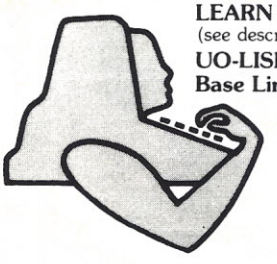
TECHNICAL INFO—WE CAN HELP. CALL

Shipping Over $200 Add 4%. $200 And Under Add 5%.
Cash With Order Deduct 3%. N.M. Orders Add 4¾% Sales Tax.
Allow 4 Weeks For Delivery.

RIO GRANDE ROBOTICS RG
1595 W. Picacho #28, Las Cruces, N.M. 88005, Tel. (505) 524-9480

(LISP) FOR A.I.

UO-LISP Programming Environment
The Powerful Implementation of LISP for MICRO COMPUTERS



LEARN LISP System (LLS.1)
(see description below **$39.95**
UO-LISP Programming Environment
Base Line System (BLS.1) ***$49.95***

Includes: Interpreter, Compiler, Structure Editor, Extended Numbers, Trace, Pretty Print, various Utilities, and Manual with Usage Examples. **(BLS.1)** expands to support full system and products described below.

UO-LISP Programming Environment: The Usual LISP Interpreter Functions, Data Types and Extensions, Structure & Screen Editors, Compiler, Optimizer, LISP & Assembly Code Intermixing, Compiled Code Library Loader, I/O Support, Macros, Debug Tools, Sort & Merge, On-Line Help, Other Utility Packages, Hardware and Operating System Access, Session Freeze and Restart, Manual with Examples expands to over 350 pages. Other UO-LISP products include: LISPTEX text formatter, LITTLE META translator writing system, RLISP high level language, NLARGE algebra system. Prices vary with configurations beyond (BLS.1) please *send for FREE catalog.*

LEARN LISP System (LLS.1): Complete with LISP Tutorial Guide, Editor Tutorial Guide, System Manual with Examples, Full LISP Interpreter, On-Line Help and other Utilities. LEARN LISP fundamentals and programming techniques rapidly and effectively. This system does not permit expansion to include the compiler and other products listed above.

LISP Tutorial Support (LTS.1): Includes LISP and Structure Editor Tutorial Guides, On-line Help, and History Loop. This option adds a valuable learning tool to the UO-LISP Programming Environment (BLS.1). *Order (LTS.1) for* **$19.95.**

REQUIRES: UO-LISP Products run on most Z80 computers with CP/M, TRSDOS or TRSDOS compatible operating systems. The 8086 version available soon.

TO ORDER: Send Name, Address, Phone No., Computer Type, Disk Format Type, Package Price, 6.5% Tax (CA residents only), Ship & Handle fee of $3.00 inside U.S. & CN, $10 outside U.S., Check, Money Order, VISA and MasterCard accepted. With Credit Card include exp. date. Other configurations and products are ordered thru our *FREE catalog.*

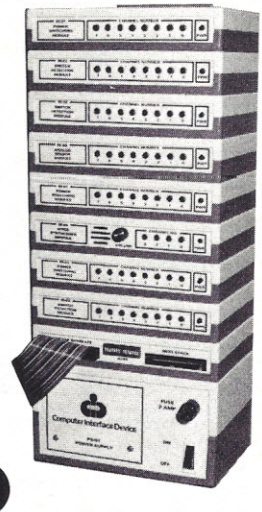
Northwest Computer Algorithms
P.O. Box 90995, Long Beach, CA 90809 (213) 426-1893

Circle 8

Let Cid do it!

Cid is the only modular, **building block**, computer interfacing system designed for people who do everything. Cid's **snap together** modules mean **maximum flexibility** that no other personal computer interfacing system can offer. Even the computers interfacing to Cid can change by simply changing a cable.

- Cid connects to most personal computers
- Programmable in BASIC and other languages
- **Fast** and **easy** to program
- Requires **no software drivers**
- Great for monitoring and controlling
- **Fast** and **simple** to setup
- Built of **highest quality**
- Nine Modules available and growing
- Available NOW!

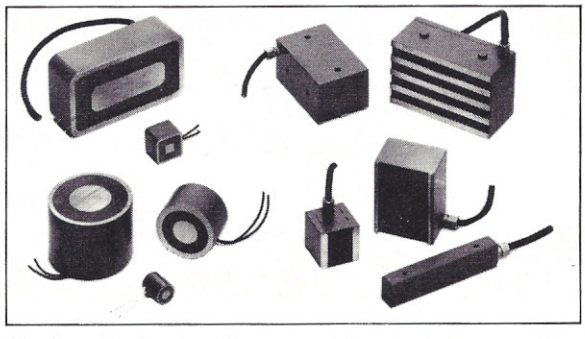


Get more facts on Cid, the **low cost** missing link that computer doers have been waiting for. Write or call today for FREE catalog.

Computer Interface Device

ELECTRONIC SYSTEMS AND INSTRUMENTS, INC.
8301 Castle • Wichita, Kansas 67207 • (316) 686-5655

ELECTROMAGNETS
Sized & Powered To Meet Your Needs



Designed, sized and powered to meet your applications, the safe, low voltage, dependable, IMI Electromagnets deliver concentrated holding power and maximum performance.

In round, rectangular, parallel pole and multi-pole configurations, with continuous or intermittent duty operation, IMI electromagnets have the size and holding power for robotic, automated systems and industrial holding, locating, positioning and separating applications.

INDUSTRIAL MAGNETICS, INC.

(616) 582-3100
P.O. Box 80
Boyne City, MI 49712
Telex No. 810-232-1528

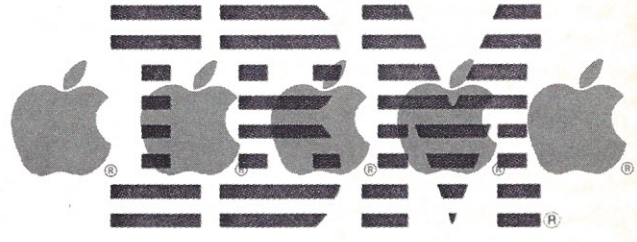
Joint Venture
Simon-Day, Ltd.
Winnipeg, Manitoba

In The Robotics Age

what, while the glass, cement, and ceramics industry segment will grow at an average annual rate of 10.3 percent.

Researchers at the Columbus Division of **Battelle Memorial Institute** have embarked on a two-year study of the impact of robots and other automation technology on manufacturers, suppliers, contractors, architects, engineers, and workers in the construction industry. Researchers will identify and analyze emerging innovations; changes in construction methods, design, and materials; and current problems and unfilled needs where robots might be technically and economically superior to present methods. The focus will be on mechanical robots and remote-control equipment and partial robot control innovations, such as using computer technology to relieve machine operators of certain tasks.

The U.S. robotics market grew by around 50 percent last year, according to a study carried out by **Robotic Industries Association**. Based on sales figures from the first two quarters of 1984, the year-end total is projected at $300 million. The study indicated also that more robots had been shipped in 1983 and '84 than in the previous 20 years combined, and that the average price of a robot had dropped from $74,000 in 1983 to $59,200 at the end of last June. According to one estimate, there are currently 13,000 industrial robots installed in the U.S. RIA is officially designated by the international robotics community to collect and report worldwide statistics. The new U.S. numbers will be included in the next edition of the Association's *Worldwide Robotics Survey and Directory*, due out later this year. ■



THE IBM-APPLE HYBRID

An exotic new robotic crossbreed has caught our eye, and we wonder if one particularly vigorous business rivalry might be nothing more substantial than Madison Avenue hype. According to a story in a recent issue of the *Wall Street Journal*, a group of high-tech securities analysts was touring Apple's personal computer factory when their attention was directed to a certain robot described by the guide as the most reliable worker on the assembly line. This reliable robot, adorned with the company's rainbow apple logo, turned out to be of IBM manufacture.

Apple's top brass defended both source and modification of the gizmo: President and CEO John Sculley allowed that IBM made excellent robotics systems and Chairman Steven Jobs was quoted as saying, "We just happen to think our logo looks better than theirs."

SPEECH RECOGNITION: MACHINES THAT LISTEN

Dr. Thomas B. Schalk
Voice Control Systems, Inc.
16610 Dallas Parkway
Dallas, TX 75248

Speech recognizers have been commercially available for nearly a decade, and many vendors now have speech recognition product offerings. Market surveys and extensive press coverage suggest strong market potential and a base of eager customers, yet the market is developing very slowly. Why is this so? One major reason has been the high cost of speech input compared to other competitive input methods such as keyboards. Another more ominous reason has been the performance shortfall of speech recognizers relative to customers' expectations and needs. The purpose of this article is to explore the capabilities and limitations of today's speech-recognition systems.

HOW COMPUTERS RECOGNIZE SPEECH

First consider how acoustic speech signals are perceived by humans. This may be understood most easily through spectrographic analysis, which has been a basic tool of speech scientists for over 30 years. Figure 1 is a spectrogram of the word "listen." This spectrogram shows the acoustic energy distribution of the word (the dark areas) as a function of frequency and time. The beginning and end of the word contain low-frequency energy; the "s" contains high-frequency energy. Of key importance to human perception are the frequencies of the mouth cavity controlled by the tongue, jaw, and lips. Determination of the first two or three formant frequencies is usually adequate to characterize the sound as it is perceived by the human ear. For example, notice in Figure 1 that the second formant frequency rises from less than 1000 Hz in the "l" to above 1500 Hz in the "i."

Machine recognition must take advantage of this same information, and it is not surprising that machine recognizers invariably include some means of representing or modeling the amplitude spectrum of the incoming speech signal. This first step in speech recognition is generally referred to as feature extraction and its purpose is twofold: to transform the speech signal to features or parameters that are recognizable and to reduce the data flow to manageable proportions. The most common method of feature extraction is direct measurement of spectrum amplitude, often done with a set of bandpass filters (typically 16).

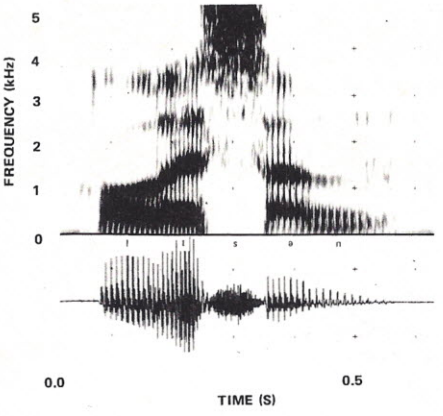


Figure 1. A spectrogram of the word "listen" is plotted from a normal level speech signal. The beginning and end of the word exhibit low-frequency energy, while the "s" exhibits high-frequency energy.

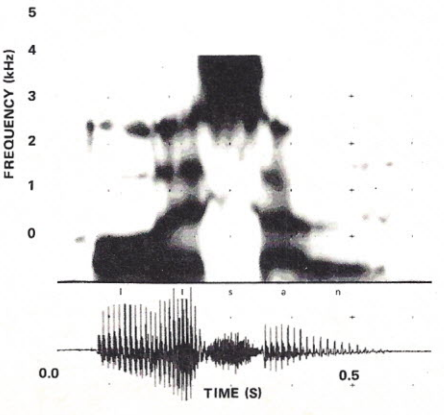


Figure 2. The Linear Predictive Coding (LPC) technique was used to model the same speech data from Figure 1 for a 30 ms window.

Another technique is to measure the zero-crossing rate in several (two to four) frequency bands to provide an estimate of the formant frequencies in these bands. A third technique, one which has become popular during the past several years, is to model the speech signal in terms of the parameters of an all-pole spectrum of the input speech signal. This technique, known as linear predictive coding (LPC), has gained popularity because of its efficient representation and because it is an excellent model for speech signals. Figure 2 shows the LPC model spectrum corresponding to the speech data plotted in Figure 1.

The recognition features extracted from the input speech represent the slowly varying state of the signal. These features, along with the signal amplitude, are typically smoothed or averaged over 10–20 ms and then sampled 50–100 times per second. At this point, this data is digitized (if not already in digital form) and subsequently processed by a programmable digital signal processor.

The next step in speech recognition is the actual comparison of the input features with the various reference patterns. Prior to this, proper time alignment of the input feature vectors must be established so that the input "l" is compared with the reference "l," and the input "s" is compared with the reference "s." Time alignment is

usually achieved by determining the beginning and the end of the word using energy criteria; the word begins at the onset of significant speech energy and ends when the speech energy drops below a predetermined threshold for a specified length of time. This time alignment problem, one of the toughest to be solved, is discussed later.

After time alignment is achieved, the input features are compared with the reference patterns for each of the words in the recognition vocabulary. First however, an input pattern must be created that is based on the end-point times established for the input word. This is usually accomplished by choosing a fixed number of feature vectors (typically 16) linearly spaced between the word end points. The input pattern is thus formatted and ready for comparison. For each reference vocabulary word, a measure of similarity is computed by comparing each feature for each time slice of the input pattern with the corresponding feature of the reference pattern. N similarity measures are computed (for an N-word vocabulary), and the reference word that differs least from the input is the recognized word. Often a rejection criterion is desirable to prevent spurious recognition output in response to incorrect or non-speech input; if the difference between reference and input is too large or if the next-best reference is nearly as good as the best reference, the input word is rejected.

The block diagram in Figure 3 summarizes the major steps of typical machine speech recognition. Usually, an enrollment mode exists in which the reference data is created specifically for the user of the system. In this mode, a number of tokens (typically four to eight) of each vocabulary word are averaged together to create a reference pattern to be used in recognition. This enrollment mode is not necessary for speaker-independent recognition.

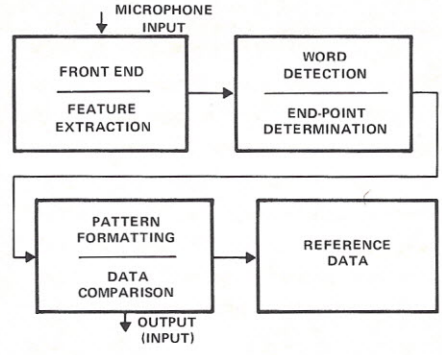


Figure 3. Current speech-recognition machines typically perform the processes shown in this block diagram.

CAPABILITIES OF CURRENT SPEECH RECOGNIZERS

The three questions that people ask most often when inquiring about the capabilities of a word recognizer are:

1. Can it recognize connected speech?
2. Is it speaker-independent?
3. How big a vocabulary can it recognize?

These are difficult questions because the answers are frequently not clear-cut.

The easiest question to answer concerns the connected/discrete-speech issue. Most currently available recognizers depend on a small period of silence (typically 200 ms) between words to determine the end points of the word. These recognizers are clearly discrete-speech recognizers. Some recognizers (notably NEC's and Verbex's) are capable of recognition without explicit knowledge of the word end points. This technology tends to be expensive because it requires much more intensive data comparison than if the word end points were known. Even these connected-speech recognizers, however, do not perform as well with connected speech as they do with discrete speech because the acoustic variation of words spoken in connected speech is greater. This is attributable to the co-articulation of neighboring sounds; the

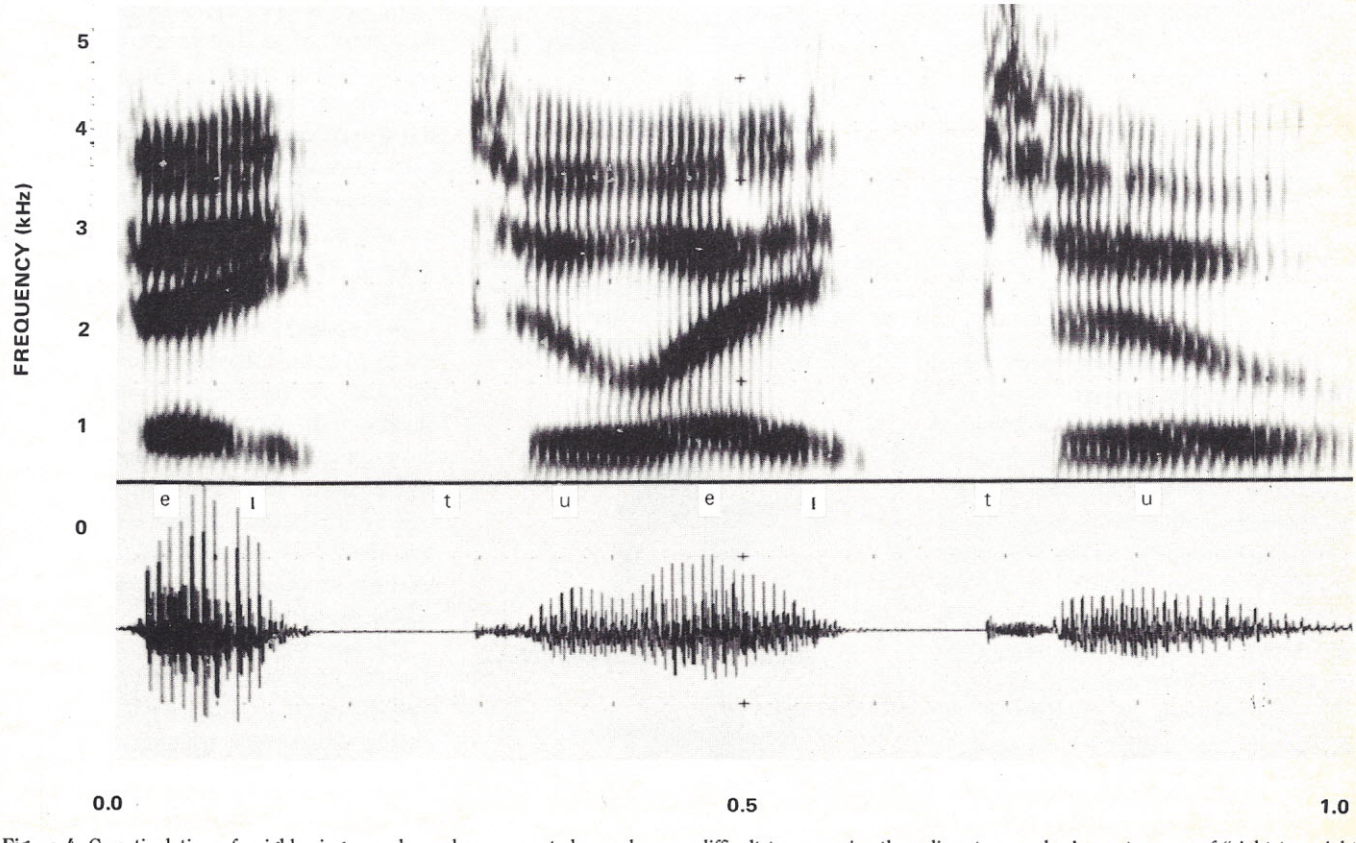


Figure 4. Co-articulation of neighboring sounds renders connected speech more difficult to recognize than discrete speech. A spectrogram of "eight two eight two" is shown.

positions of the tongue, jaw, and lips in one speech sound are affected by their previous and future positions. An example of this is demonstrated in Figure 4.

Two factors must be considered when discussing the speaker-independent issue. First, currently used features are relatively sensitive to speaker characteristics that are relatively transparent to the human ear. For example, Figure 5 displays the spectrogram of the word "listen" for a speaker different from the one shown in Figure 1. Notice the differences in the formant amplitudes and in the time course of these two utterances. These differences invariably result in performance degradation when speaker-independent recognition is attempted. Recognizers intended for speaker independence usually include several (or many) reference patterns for each vocabulary word, so that the reference data represents almost all speakers.

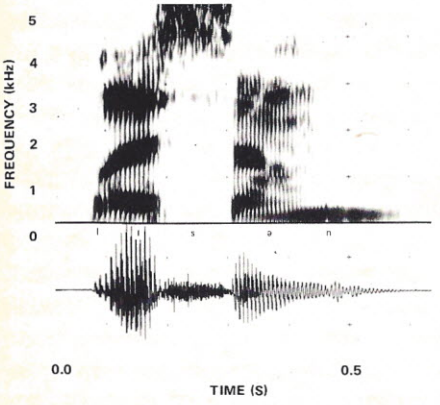


Figure 5. Performance is degraded when speaker-independent recognition is attempted. This spectrogram is for the word "listen" as in Figure 1, but for a different speaker. Note the different formant amplitudes and time course.

The second factor to consider is the statistical distribution of performance as a function of speaker over the user population. Frequently, a speaker-dependent recognizer that performs well for the intended speaker will perform passably well for a different speaker, which can lead to the misconception that it's speaker-independent. Unfortunately, performance varies radically from speaker to speaker (even for those recognizers that claim speaker independence), and performance for speaker-independent recognizers really needs to be characterized in terms of population performance statistics. For example, "the recognizer performs with E percent or less error on the best P percent of the population." The objective of speaker-independent recognizers is to minimize E and maximize P. The fact remains, however, that speaker-dependent recognizers perform better than speaker-independent recognizers.

On the issue of vocabulary size, there are two factors to consider. First, can the machine do the work? Because computer processing time is usually dominated by input/reference data comparison, and the amount of comparison required is linearly proportional to the size of the vocabulary, can the recognizer keep up with the incoming speech data? The second factor is usually more important—what happens to recognition performance as the size of the vocabulary is increased? Often, performance degrades to an unacceptable level before the processing capacity of the machine is reached.

Of course, error rate is not strictly a function of vocabulary size. The real issue is how similar the words are in the vocabulary. Performance tends to be better for vocabularies consisting of long multisyllabic words. Most important is the particular composition of the vocabulary in terms of the acoustic similarity of the various words to one another. For example, even a two-word vocabulary might be impossibly difficult. Try "seen" and "seem" the next time a word recognizer is being evaluated.

PROBLEMS IN USING CURRENT SPEECH RECOGNIZERS

Of all the problems that burden the use of current speech recognizers, probably the greatest is the difficulty in reliably determining word end points. End-point misalignment is often responsible for almost all word-recognition errors in the typical operation of discrete word recognizers that base reference comparisons on an initial determination of end points. This end-point detection problem does not exist (or rather, is solved in a more comprehensive way) for connected-speech recognizers. Therefore, connected-speech recognizers have a potential for better performance in discrete-speech applications. The spectrogram in Figure 6 illustrates some of the problems in end-point detection.

Speech sounds have a wide range of amplitude and time profiles, causing difficulty in discriminating them from noise. There is also considerable variation in the way a speaker articulates a word; he will sometimes articulate a final "t" and

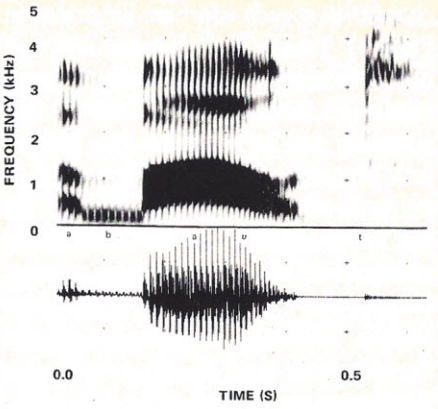


Figure 6. End-point detection is difficult with low amplitude signals. This spectrogram is of the word "about" and shows the potential end-point detection problem.

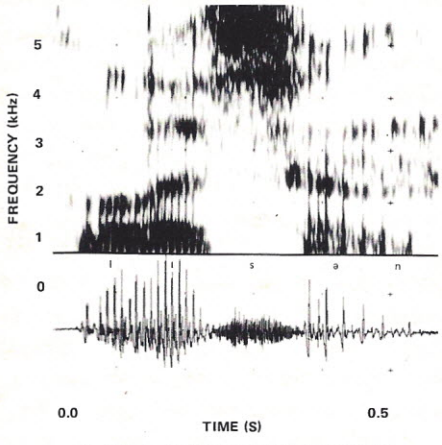
sometimes not. In addition, the noise includes aspiration after speaking a word and quick inhalation or lip pops immediately before speaking. This does not happen on every word (we hope), but remember that we are trying to achieve relatively high performance. If our performance goal is 1 percent error, then a reasonable demand is satisfactory end-point detection at least 99 percent of the time.

The most disastrous time for mistakes in end-point detection is during speaker enrollment. This can and often does create a rather common condition that is known as bad enrollment. When this occurs, the speaker must be reenrolled for the offending word. The problem is not so much that reenrollment is necessary, but rather that the need is not known until sufficient negative results are experienced to mandate the reenrollment.

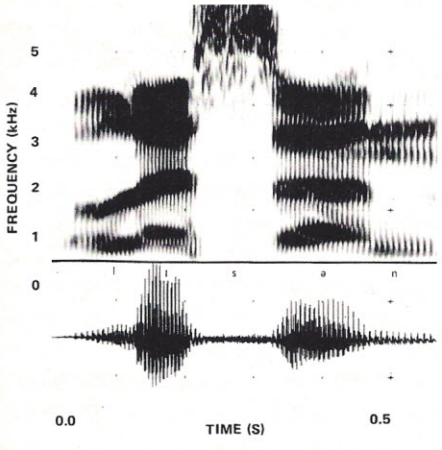
Running a close second to end-point detection problems are problems in the consistency with which a speaker pronounces words. Indeed, inconsistency contributes to the end-point detection problem as discussed above. Many physical and psychological factors contribute to variations in a speaker's pronunciation. Although little is understood about how such factors affect speech, we observe that speech data in a single session is much more self-consistent than speech data produced over a long period of time. The source of this variation may not be totally attributable to the speaker; other sources include variations in the environment (noise and reverberation) and in the microphone placement.

A speaker may improve the acoustic consistency by controlling speech effort level. The dramatic changes that take place with

changes in speech effort are illustrated in Figure 7. Usually, the tendency of a new user is to speak much too softly. (Several reasons for this might include the fact that a speaker may be intimidated by the system. The microphone is usually positioned no further than an inch or two from the lips, which implicitly commands a very low speech level.) Low speaking levels promote inconsistency because of irregular voice excitation. A low speech level also reduces signal-to-noise ratio. Shouting would cure these problems and would be acceptable, except that consistency would be rather short-lived before hoarseness of the user and general disruption of the social environment occurred. The preferred speech level is that of an authoritative, confident, across-the-desk conversation. If this speech level is maintained, the new user has made an auspicious beginning.



A) LOW SPEECH (SOTTO VOICE) WITH LESS HIGH THAN LOW FREQUENCY ENERGY IN VOICED REGIONS AND WITH LAST SYLLABLE TENDING TO BREAK FROM REDUCED GLOTTAL AIR FLOW



B) HIGH EFFORT (SHOUTING) SHOWING MORE HIGH THAN LOW FREQUENCY ENERGY IN VOICED REGIONS AND DIFFERENT AMPLITUDES OF VOWELS RELATIVE TO CONSONANTS

Figure 7. Figure 7a gives the spectrogram for a person speaking in a very soft voice, while Figure 7b shows the effect of shouting on the quality of the acoustic consistency. "Listen" is again the word being spoken.

Not all users will be equally successful in using currently available speech recognizers. This problem was discussed in the context of speaker-independent recognition, but the same problem occurs even with speaker-dependent recognizers. Differences in performance for various users may be partially attributable to the experience of the user, but beyond this a very strong individual variation in recognition performance still remains. This variation has been observed many times and has given rise to the user categories designated "sheep" and "goats." Although a continuous spectrum of performance occurs across all users, it appears that recognition systems generally work well for the bulk of the population whom we call the "sheep." Most of the problems are created by a small segment of the population whom we call the "goats." This categorization has been most convincingly demonstrated with statistics gathered from a voice verification system that has been used at Texas Instruments for the past eight years to control entry to TI's corporate computer center. One of the primary performance parameters of this system is the probability that a valid entrant will be rejected because of voice mismatch. Statistics on these rejections reveal that more than three quarters of the population are better than average and that the typical (median) user has a probability of rejection that is less than half the average value.

The performance of machine word recognizers is also affected by limitations in the reliability of human speech performance. Similar problems are occasionally experienced in conversation with other humans, and these problems are solved through intelligent interactive feedback. These problems are solved in a like manner for machine recognition. In this case the reliability of the human is of greater concern because of the larger set of rules that he must follow and, therefore, the greater the opportunity for making mistakes. Probably the greatest reliability problem for humans is the word separation required by discrete-speech recognizers. In the first place, we have observed that speaking discretely is not necessarily a skill that is intuitive or trivially acquired. One must learn to speak crisply and to leave the required gap (plus a safety factor) between words.

In the second place, the implicit demand for high recognition throughput requires that this safety factor be no greater than necessary. What is necessary? The sense of what is necessary and the ability to achieve high throughput are honed only by experience in committing word gap violations. With this perspective, it is clear that discrete-speech errors are an important factor in the performance of discrete-speech recognizers. Connected-word recognizers, by contrast, have the advantage of a gradual degradation of performance with decreasing size of the gap.

Another human limitation relates to the size of the recognizer vocabulary. As the vocabulary size is increased, there may be a problem in the human recollection of the vocabulary. This is particularly true if portions of the vocabulary are seldom used—a frequent situation for large vocabularies. This human limitation may be overcome by experience or by visual displays, but it is a problem that needs to be considered by potential users in judging the suitability of their intended applications.

To summarize, limitations of current speech-recognition technology create problems for the user that must be overcome. The theme of successful use is learning and adaptation. People normally need training and practice to become proficient with current speech recognizers. It has been observed repeatedly that experienced users do better on the average than new users. This is a characteristic that the new user needs to appreciate.

Dr. Thomas B. Schalk is chief technical officer at Voice Control Systems, Inc., where he directs research dedicated to the development of low-cost, speaker-independent speech-recognition technologies.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

70	80	90
Excellent	Good	Fair

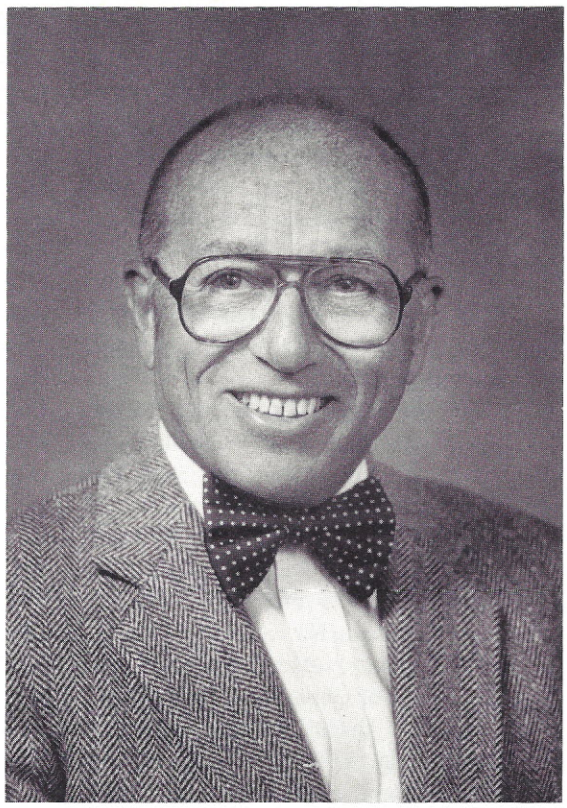
JOSEPH ENGELBERGER: THE FATHER OF INDUSTRIAL ROBOTS REFLECTS ON HIS PROGENY

Alfred B. Bortz
1312 Foxboro Dr.
Monroeville, PA 15146

When Joseph F. Engelberger appears as an after-dinner speaker, the announcer invariably identifies him as "The Father of Industrial Robots." As the founder of Unimation, Inc., the world's first robot manufacturer, Engelberger undoubtedly deserves that accolade, and he accepts it with a mixture of pride and amusement. He smiles and puts it this way: "Sometimes people say, 'Aren't you proud to have your name on a lot of the patents?' and I say, 'What I'm proud of is that I was able to get the money when no one believed.'"

That statement is characteristically Engelberger. His insights are often startling, and, despite his technical accomplishments, he makes his points in human terms. He frequently slips into the conversation-within-a-conversation mode, playing the role of another person enthusiastically, complete with gestures and inflections.

Engelberger is ingratiating. His eyes, voice, and manner of speaking convey enthusiasm. His owlish glasses, close-cropped, well-receded hairline, and his trademark, a large, jaunty bow tie, remind you of your favorite professor.



Joseph Engelberger, founder of Unimation, Inc., is now a consultant for the Westinghouse Corporation's Energy and Advanced Technological Group, to which Unimation belongs.

Engelberger's brainchild, the industrial robot, has now reached young adulthood. Like any parent, Engelberger can tell you the tribulations of helping his offspring reach maturity. And what of the new generation of robots? Engelberger has definite ideas about how they should be nurtured and what is expected of them. His wisdom, rooted in his experiences as a roboticist and a businessman, provide a historical perspective and valuable guidance for future developments in robotics.

J. ENGELBERGER, ENTREPRENEUR

Robotics is an entrepreneurial endeavor. True, the manufacture of first-generation robots has become a production business. But building the second generation of robots (those with greater flexibility and dexterity, trackless mobility, senses, or decision-making intelligence) and integrating them into systems still calls for invention and risk-taking. Those entrepreneurs who intend to follow in Joseph Engelberger's footsteps would be wise to listen to him describe the terrain.

When Engelberger began to study physics (he has B.S. and M.S. degrees from Columbia University), the word "robotics" had not yet been invented. But while he was studying, another physicist was imagining and writing. Isaac Asimov wrote a series of short science fiction stories in the 1940s, nine of which were collected to become the classic *I, Robot*. Unlike the malevolent robots in Capek's *R.U.R.*, Asimov's robots were particularly well-designed machines of great value to humankind and were strictly benign. Their positive qualities were assured by strict adherence to design codes that incorporated the "Three Laws of Robotics."

In his forward to Engelberger's book, *Robotics in Practice*, Asimov writes, "I did not at that time seriously believe that I would live to see robots in action and robotics becoming a booming industry." Imaginative as Asimov was, he could not conceive that a young entrepreneur-to-be, one J. Engelberger, would become hooked on robots and Asimov's coined word, "robotics."

When Engelberger finished his academic career, he served with the Navy in the Pacific on the A-bomb test program. After he got out of the Navy, he went to work in the aerospace industry, becoming an expert in servocontrol technology and a manager of a division of a major com-

pany making aerospace and nuclear controls for the military. But not until 1956 did his career take a decisive turn toward robotics. In that year, at a cocktail party, he met George DeVol, who had a patent on a programmable manipulator.

Engelberger believed that DeVol's device had wide application and could be marketed. He persuaded his employer to take a license on it and to let him set up a group to develop it into a product line. But in 1957 he had a falling out with his employer. The company wanted him to abandon work for the military and to liquidate his division. The manipulator project was also to end. But Engelberger believed too much in his division's work to let it die. He and some of his colleagues persuaded their employer to let them buy out the operation, and Consolidated Controls was born.

By then, Engelberger had dreams of building robots, but his first priority was to get the new company off the ground. It didn't take long. Within months, the company became profitable, and it has increased its profits each year since then. A year after starting Consolidated Controls, buoyed by the success of his venture into risk-taking, Engelberger was ready to follow his dream. He reactivated his belief in DeVol's invention and took a far greater risk. This time he set out to begin not just a company but an entirely new industry—robotics.

PROTOTYPE TO PROFITS: A LONG ROAD

How does a person launch a new industry? Engelberger did it with a survey. He asked key people in the automotive industry and in manufacturing businesses in the Bridgeport, Connecticut, area, "If you could build a robot, what would it do?" What happened after that is best told in Engelberger's own words: "We tried to come up with the characteristics of a machine that would take the place of a human in hot, heavy, hazardous type jobs. We had very little money at the time. We scraped along. And when we finally got a prototype out [in 1959], then we said, 'Well, no way can we mount the kind of an effort it's going to take.' And we went out and raised money again."

Raising money is the toughest part of being an entrepreneur. No matter how deeply you believe in yourself and your ideas, convincing other people is a difficult job. In the preface to his book, Engelberger pays tribute to those he convinced: "An imaginitive entrepreneur, Norman I. Schafler, founder and still chief executive at Condec Corporation, dug down first, and he was later joined by Champ Carry, then chairman of the Pullman Corporation," which bought 51 percent of the new business, Unimation, Inc.

"...we installed our first robot in 1961; we made our first profit in 1975."

But the road from prototype to profitability was long. "We had a few technical difficulties, but more than anything else we had the barrier of people not believing that this kind of robot nonsense is for real. We could get on the Johnny Carson Show, and we could make coffee and drinks, but getting into factories is a little bit harder. To put it another way, we installed our first robot in 1961; we made our first profit in 1975. So for 14 years this was a drain with nothing coming in."

How did Engelberger manage to maintain his confidence in Unimation over those difficult years? He says that understanding the developmental process of technological innovation was the key: "I studied an awful lot to determine the characteristics of innovations like the Polaroid camera, N.C. machine tools, piggyback railroads, automatic bean-picking—not Hula Hoops, but real technological innovations. Almost without exception, there's a plateau when nothing happens from the day in which it's technically feasible to the day in which it becomes economically viable, and that plateau runs 10 to 15 years. Then it gets on a classical exponential curve and grows to maturity. It was encouraging in a way to say, 'Well, we're still on this flat. We've proven technical feasibility; we just haven't gotten the economic justification.'

"Another negative encouraged our thinking. There are two kinds of innovations. There are innovations that come from within: For example, a new chip in the electronics industry gets adapted very, very fast. But there's also innovation by invasion, and we were invaders. N.C. machine tools took a long time because the machine tool companies didn't develop them. The Air Force developed N.C. machine tools and stuffed them down the companies' throats. We were stuffing down the throat. It was hard to do that.

"The final thing that was very important [for maintaining confidence] was a 1968 study by the Air Force called Project Hindsight. [The report] said, 'Gee, if we look back on successful innovations and failed innovations, what are the characteristics of an innovation that give you a chance of succeeding?' The first thing is a perceived need. The next thing is appropriate technology and accomplished practitioners of that technology. And finally, you have to have sufficient financial support. If you miss any one of the three, you're not going to make it.

"So looking back now, we can see why we didn't have robots, for example, in 1922 when the word first came into the English language [from *R.U.R.*] or in 1936 when Charlie Chaplin did "Modern Times." The evidence was there: the robot would have made sense. The perceived need was obvious, but the technology...

"Servotechnology was born in World War II. We had automation, but we never had servos that could go into position [with infinite adjustability] before then. We had knowledge of Boolean algebra, but we didn't have digital technology at all, and we didn't have solid state electronics. After World War II, the technology came. Out of aerospace came the people.

"So now we had the technology, the people, the perceived need. Money was the tough thing to come by. But things were improving because of labor costs. At the time of Chaplin, labor was cheap, plentiful, and intimidated. But after World War II, it wasn't cheap and intimidated any longer. And today, of course, the economic pressure is very high. When we installed our first robot, labor in the automotive industry was getting $3.80 an hour, including fringe benefits and everything. Today it's about $19.00. A robot today, including depreciation of the money, service, maintenance, and every element of cost, comes to about $6.00 an hour. That drew the money to the game. Finally we had perceived need, tech-

nology, able people doing it, and the money. And robotics succeeded."

WHY NOT CALL IT A U-T-D?

Robotics succeeded. But, as in any new industry, success requires more than those ingredients Engelberger mentioned. It needs marketing; it needs "good P.R." Engelberger knew that instinctively. And he knew that the best public relations available was the name itself. This is how he explains it:

"A phrase like 'computer-aided manufacturing' is kind of nebulous. But ROBOT! There's hardly anyone who isn't slightly embarrassed if he doesn't understand 'robot'—even if he *doesn't* understand 'robot.' You know, 'Yeah, sure, I know robot; I've been to *Star Wars*. I know all about it.' The word is catching.

"Nonetheless, it was difficult in the beginning to hold onto the word. Everyone said, 'No, don't call it a robot. That's bad. Let's call it a production terminal.' Ford Motor Company insisted it was a Universal Transfer Device. 'U-T-D,' they called it for short. The purchasing department said, 'Wanted, three UTDs,' and in parentheses they'd write, 'Industrial Robots,' so you'd know what they were talking about! The word was important. We needed all kinds of publicity to get the idea across. And 'robot' was the right word."

"That's part of the inertia of manufacturing. We have perhaps 450 robots that are in die casting, which is one of the more miserable jobs. But I would guess that (including our competitors) we still have hit only about 25 percent of the applications.

"Forging is another place, but an awful lot of forging equipment is very archaic. It's so bad that the robot can't work [there]. They depend on the human to dig the parts out and to live with the problems that exist in an old foundry. As the companies upgrade the forging equipment, then robots can come into that environment."

Because of the heavy spot-welding gun and the tedium of the job, spot welding is the single biggest robot activity in the world. But Engelberger estimates that the 6000 robot spot welders represent only about a 50 percent saturation of the market.

Arc welding represents a huge target of opportunity for the robotics industry, but first-generation robots can't meet the needs of the job. Some kind of robot vision to locate and track the seam (such as the Automatix, Inc., systems discussed elsewhere in this article) is needed.

How large a target of opportunity is arc welding? Engelberger estimates that it is 20 times as large as the opportunity in spot welding. "Maybe the torch isn't so heavy, but the environmental conditions are very severe," he explains.

"...all the jobs are out there still, and the people who are not using robots for them are putting themselves at a serious economic disadvantage."

NEW MARKETS FOR OLD ROBOTS

Although new technologies are evolving rapidly in the robot business, the market for first-generation robots (deaf, dumb, and blind programmable manipulators) remains strong. Concerning the hot, heavy, and hazardous jobs that industrial robots are famous for, Engelberger notes that "The various activities that robots now do, [those which] have been absolutely proven, are not at all saturated. All the jobs are out there still, and the people who are not using robots for them are putting themselves at a serious economic disadvantage.

ROBOTS IN ASSEMBLY

Beyond the three H's—hot, heavy, and hazardous—robots have great potential in another class of distasteful human jobs: tedious and repetitive jobs in which boredom often leads to inattentiveness, accidents, and poor quality. Assembly tasks are among the most tedious, and Engelberger sees them as one of the prime areas for expansion of industrial robotics. He cites palletizing and conveyor transfer as simple examples of activities in assembly plants.

"It seems so simple, and yet it isn't quite that simple. All over our industry, there are people who take a part from this conveyor and put it on that conveyor because it's going from this subsystem to that subsystem. Now, if you watch carefully you'll find that there's not always a part here. There's not always an open hook here. And therefore that human being has to take a few steps in different directions to match up these things so that they come out even in the end.

"Now, that means we have to have some sensory perception with the robot because it's got to decide, 'Is there something there or isn't there? How fast are they going?' I'd better sense speed so I know that I can get it on the conveyor while it's moving.

"Next, suppose I end up with a whole pile of things coming in and no empty hooks. What do I do? I'd better put them down on a pallet and remember where I put them, because later on there's going to be nothing coming in but empty hooks and I'm going to take them out of my buffer storage.

"All of those things are accepted, out of hand, as human qualities, but they're not so easy to come by in a robot. But that's a tedious job that robots now can do."

Assembly Problem 1: Bin-Picking. "Unfortunately, despite all you hear, there's a lot of missing technology," Engelberger continues. "The robot is already good enough to do the assembly, but the robot is not good enough to find the parts that are placed at random, what the trade talks of as the bin-picking problem or the engineer talks of as the occlusion problem. How do we get around the fact that a human—an idiot—can pick things out of a tub one at a time and orient them in his fingers while moving to the next station? We don't have any answer for that."

At the University of Rhode Island, electrical engineering professor Robert B. Kelley has designed a research effort to find the answer. Kelley's assessment is that "Bin-picking is at a primitive stage of development, but it can work for a large variety of the most common parts encountered in industry."

Of Kelley's work, Engelberger says, "He's done a number of interesting, good things. But there's no possible prayer of what he's done so far being economically justified. Most of what he does requires grasping and regrasping and viewing between the two. He finds that if you get the part

isolated and you give it a few views in front of a camera, then you can determine where the surfaces are. Then you must put it down and grab it again and get on with it. That takes too long.

"There are other problems. One of the things that happens with jumbled parts—there's a whole mathematics tied to this—is that they are self-organizing. You shake them in a box and they interlock. They come out in chains. They may end up being so occluded that there's no place to grasp. So [Kelley's group] came up with suction-cup fingers and magnetic things to pick them out. [But] the generic problem isn't solved, I assure you."

Assembly Problem 2: The Irrational Workplace. Assembly is the process of taking parts, putting them into the proper orientation with respect to each other, and putting them together. Putting them in the proper orientation costs money, so preserving orientation is worth money. Often preserving orientation makes the difference between being able to use robots and requiring human labor for a distasteful job. Robots work best in an orderly, or rational, environment.

SOFTWARE FOR MOTION CONTROL

Intelligent software utilities for stepping motors and real world control.

- 6 AXIS MOTION + I/O port control
- COORDINATED motion for geometric interpolation
- LINEAR ACCEL/DECEL, END VELOCITY, and TRAVEL TIME selection
- Allows use of existing hardware
- Frees program developer to write high level tasks
- "C" and Assembly Interface
- Available for 8085/8080μp with parallel port and interrupts

REAL TIME LOGIC
8306 Wilshire Blvd., Suite 355
Beverly Hills, CA 90211
(213) 934-3667

Circle 18

"You recognize that you want to do assembly by robots, and therefore you rationalize your workplace," says Engelberger. "Almost everything was once oriented. It all started out as dirt, maybe, but eventually it got oriented someplace. And what we do is we throw the orientation away. You've got to pay for it someplace, to reorient it. So lots of times I go through a factory and I say, 'Hey, wait a minute! Why have you got these lying around in a tub when over here they came out of a machine one after the other? Why not put them on a pallet so we know where they are?'"

Part of the problem is that the parts manufacturer has no interest in preserving the orientation for the customer. But, as Engelberger points out, the problem exists even between different departments in the same plant. "Every department tends to be a profit center, and they want to deliver it to the next department in the cheapest possible way. The cheapest possible way is to throw it in a box. If you were to provide dunnage instead and orient the parts, the net cost of the total process would be cheaper.

"If you go to the factory manager and say, 'Have you got a scrap report?' he says, 'Sure, I've got a scrap report. Last month it was 2 percent. I'm down to 1¾ percent on my scrap.' I say, 'Now take orientation. Every single time you have something oriented and you throw it in the tub, give yourself a scrap ticket because you've just scrapped value.' Orientation is value just as sure as a well-machined part is value—and they scrap it!"

Of course, a bin-picking robot could also solve the orientation problem. Of this alternative, Engelberger says, "I think invention is now necessary. Given invention, I'm ready to go. Hey, beautiful! I've got a bin-picking robot. You don't have to worry any more about orientation."

Assembly Problem 3: Effective Use of Capital. Rationalizing the workplace is not the only institutional problem, says Engelberger. "Another thing, very important, that the Japanese are catching onto much faster than the Americans and the Europeans is that assembly [by humans] is a labor-intensive activity, but the minute you robotize assembly, it becomes a capital-intensive activity.

"You do not stop. You must run it around the clock. In this country, they know that when you have a big punch press, you run it around the clock. [But they don't yet realize that fact for robotized assembly.] To get that institutional thing across to America is going to be extremely difficult."

But what if you don't have the market to run it around the clock? "You always do," answers Engelberger. "That's the beauty of it. It depends on how many robots you use. What do you do when your market goes up when you're using human beings? You hire more of them, right? You put in more benches. You do the same thing with the robot. If human beings were willing to work around the clock, I'd take a third as many and work them around the clock."

Assembly Problem 4: Product Design. Yet another institutional problem facing automated assembly is the need to consider manufacturing problems from the earliest point in design.

"We did a two-armed robot job for Ford Motor Company to assemble a governor assembly for an automatic transmission. It was a very interesting one. It was 14 pieces—aluminum castings, servovalves, springs, things that took hand-to-hand coordination. With much agony, we finally did that job at one and one half times the speed of a human. But I think the critical statement in our report to the customer was nine design changes that wouldn't have cost a penny more to do: change a form tool, change a location, put a lead on a screw, get rid of square holes, get sloped holes so that things would go together much easier for a robot.

"And if they designed it with manufacturing in mind, the fact is even without a robot it would have gone together much easier. But the human is so facile that we spend human traits very cheaply. We throw them away casually, and then we're stuck with it because of the fact that the human could stick this spring in, hold it down with one finger and stick the next thing in very easily. 'All right. Works, right?' [the manufacturing people say]. And that's the end of it!

"Ever watch somebody assemble a toaster? There isn't a prayer of a robot assembling a toaster! There are more damn little springs that are hooked over things. And robots are not going to do it until you have a new design. You must start out by saying, 'Look, we want it designed so it can be made [by robots], and that's a tough thing to sell.'

"Take the automobile industry. Who's God in the automobile industry? The guy that styles it. Next behind him, the second-level God, is the guy that meets the Environmental Protection Agency things, the gas mileage, all of that, the function. At the end, when these guys are through, they throw it in the factory: 'Make it!' No one has thought all along about the poor bastards that have to make it. 'Don't you touch the style! Don't you touch anything that we did! Just find a way to make it!'

"If, at the very beginning, they had a CAD system that would slap the wrist of the designer and say, 'Wait a minute, while you're at it, change it so we can make it. You'll still get your styling in.' That is going to be very important in assembly. Design the product so it will go together properly. That's rationalization at the design level."

Eventually, robots will take their place in assembly, Engelberger concludes. Some inventiveness will be needed, but the problems are mainly institutional. "It's not going to happen overnight. We've got a tough learning cycle to go through."

THE ROBOT ASSEMBLY GAME

When he speculates on future robotic capabilities, Engelberger starts with a favorite story to illustrate current capabilities. He calls it "The Robot Assembly Game." "It's very low-budget," he says. "Anybody can play. You just make believe you're a robot and you'll see what's involved.

"First thing you do is rub petroleum jelly on your glasses. Second thing you do is tie one hand behind your back. Suppose the assembly requires the use of two hands. Very easy. Get a friend to rub petroleum jelly on his glasses and tie one hand behind his back. Then you put mittens on. And then you pick up chopsticks. Now you have arrived at the current state of robot assembly that enables you to assemble, according to detailed instructions, anything at all.

"You may think I'm using hyperbole, but [the reality] is very damn close to that. The eyesight is limited. The physical ability is limited. The hand-to-hand coordination is not there. The sensory perception is not there. And then, the assembly process is next to impossible according to the detailed instructions, as all of us know who have tried to assemble Christmas presents for our kids."

NEW TECHNOLOGIES AND ADVANCED ROBOTIC APPLICATIONS

The Robot Assembly Game makes for entertaining presentations, but Engelberger is looking forward to the day when it is obsolete as a conversation piece. He knows that new technologies, now emerging from the laboratory, will soon find their way into manufacturing and assembly. He also foresees that other technologies, still in the research stage, will lead to feasibility, within a decade or so, of applications that are now considered to be in the realm of science fiction.

Robot Vision and Tactile Sensing. Sensory perception can make robots aware of their changing environment and open up a vast array of new robotic applications. But robot senses are not nearly so general or sophisticated as their human counterparts, nor do they need to be.

Seam tracking, Engelberger says, "is a highly specialized thing and very worthwhile. Just take the arc welding application. You've got to find out where to put [the weld]. You also really ought to be watching the quality of the welds. If you have enough information coming in, you can handle both the quality and the location. There are many problems that have to be solved, and it's worth doing because it's a big market.

"I have a lot of respect for [Philippe] Villers and his crew [at Automatix], and I'm sure that they and we and others will have our respective answers. But it's a very specialized vision system, and doing seam tracking is justified in its own right. The same thing would apply to brazing, to putting the finishing joints on automobiles, to laying glue, laying sealer. There are a lot of things like that where you can use vision.

Present robot vision systems are, Engelberger continues, "specialized instruments, not an eye. It's not looking and seeing things like you and I do. It's just specialized for that kind of inspection. All kinds of inspection vision are coming along well. But if you want to know orientation and placement of parts—back to the bin-picking problem—that is the real barrier in vision.

Sonar — Stepper Motor Controller — Digital Interface

Interface your IBM® PC or Apple® IIe to the real world for robotics, process control and security applications.

- **Digital Interface Board**—24 lines of programmable digital I/O, TTL compatible, dual row header connection for user interface.*
  IBM® Version — DIB 0101 $89.00
  Apple® Version — DIB 0201 $79.00
- **Stepper Motor Controller/Driver Boards**—Drives 6 stepper motors at variable speeds using assembly language subroutines. Half or full step modes are user selectable. External, buffered driver board (included) accepts user's power supply and motors.**
  IBM® Version — SMC 0103 $299.00
  Apple® Version — SMC 0203 available soon
- **SONAR-I/O Board**—SONAR ranging unit with transducer provides distance measurement up to 40 ft., with single or multiple object returns available. 16 TTL compatible I/O lines also available.**
  IBM® Version — SIO 0102 $225.00
  Apple® Version — SIO 0202 available soon
- **SONAR/Stepper Motor Controller Board**—Best features of all above—SONAR ranging and control of 4 stepper motors. Includes controller board, transducer, external driver board and software.**
  IBM® Version — SSC 0104 $399.00
- **AC Power Control Module**—Controls 4 110 Volt resistive loads, and/or small inductive motors at 15 amps total current. Must be used with DIB 0101 or DIB 0202 boards. ACM 0103—$129.00

* Comes with example program listing.
** Comes with software on PC-DOS disk.

COMING SOON! EPROM Programmers for both IBM® and Apple® computers. Programs 2716, 32, 64 and 128.

IBM is a trademark of International Business Machines Corp.
Apple is a trademark of Apple Computers Inc.

PRI

For more information about these products, write:
PRISM Robotics Inc., P.O. Box 9474, Knoxville, TN 37920
(615) 573-4944
Use money orders for faster delivery.

Circle 17

"I have more people come in here with a vision system. They say, 'Throw 30 different parts in front of my machine and we'll tell you what it is.' I say, 'To hell with that. I know what everything is in a factory.' It's like a guy once said to me, 'People come in with inspection and I tell them I never expect to see a Chevrolet come down a Ford line. So don't tell me you know how to tell what it is. We *know* what we got. Tell me where it is.' That's the kind of vision that I think is going to be essential.

"Now, there is room beyond that to do tactile sensing as well. Recognition by tactile is something all of us can do pretty well. But it's not as critical to a robot as sensing contact forces. If you move a pencil through the air to the paper, you're using proprioceptive signals to begin with, some vision feedback. But as soon as you come into contact, you go into tactile. You instantaneously change the mode that you're operating in. If you were to blindly reach behind a panel and you wanted to put a nut on, you'd backthread until you feel the force change, then you would know that the alignment was right and you could put it on."

Robot Mobility and Voice Communication. Trackless mobile robots will literally and figuratively open doors to the future. Engelberger considers mobility a must, or at least a large plus, in many applications.

"There are plenty of jobs in which we should have mobility, where the robot should roam from place to place," he says, citing the example of a textile plant, where a robot could travel around changing bobbins. It would sit idle too long to be economically viable if it could not move around to service machines as they need it.

"There are jobs where there's processing going on: battery plants, things of that nature, where you want to do a little something at each location and move around. But mobility is going to come into its own as we get outside the factory because mobility is going to be essential for the service type jobs, and that's the next big arena (after assembly), fast food, garbage collection, hospital attendant, prosthesis: a mobile robot under voice communication. Voice communication becomes another essential thing if there's a tight interface with a human being."

Mobility and Engelberger's Dreambook. The robot as prosthesis for a quadriplegic is one of Engelberger's dreams. He speaks fervently of a voice-controlled mobile robot as "a true extension [of the tragically immobilized person]. As a roboticist I say, 'My God, look at the magnificence of that person with no mobility: a brain, eyes, and a mouth that we could never hope to emulate!' And we leave the person a vegetable."

Adding all the features together, Engelberger says, "So if I have voice communication in a mobile robot with vision and tactile sensing, we're getting close to a household robot, which is the [last page] in my dreambook of what you can really do with a robot—truly useful, not a toy."

Engelberger recalls an argument with an architect who wanted to make a kitchen in a room separate from Engelberger's office. "I said, 'I want it right here in my office so that I'm going to be able to have a robot called Isaac, in honor of Asimov, in the closet here. It's going to come out under my voice command and make coffee and Danish for my guests, and it's going to come in and pick up the dishes and wash them.' That'll be an example of how you can work with a robot. I think that by 1990, it will be completely practical. And before that, there will be other things practical, like a gas station attendant."

Other Mobile Robots. When they think of mobile robots, many engineers envision robot coal miners and robots in inaccessible places such as space. Engelberger doesn't foresee those applications to be as likely to develop as his Isaac. "In coal mining," he explains, "the mobility is important. But on the other hand, so far nobody has been able to handle the sensory perception problem. There are a few things you can do, like put the rods into the overhead. But at the coal face, where the action is, no one has been able to lick that problem.

"The one in space—the one they have so far—is not really a robot. It's a manipulator. It works under control of a person in the loop." When asked about the projected Mars Rover, which could not have a person in the loop because communication has a 20-minute lag, Engelberger was skeptical. "So it's got to do some decision-making on the scene," he replies. "That's what the Russians told me when they wanted to exchange license information. They said, 'Well, you people had to send people to the moon. We sent a robot.' And all their robot did was take a shovel of dirt.

"Most exotic type things, undersea and so forth, can afford to keep the human in the loop. And when the human is still in the loop, I don't class that as a robot. That's a personal prejudice. The human's in the loop; it's just an extension of the human being."

Artificial Intelligence. Some university researchers (such as Herbert Simon, whose comments were discussed in *Robotics Age* March/April 1983) view robotics as a testing ground for applied artificial intelligence (AI). Although he recognizes that it has value, for example in developing speech-recognition capabilities for voice control, Engelberger has a different view of AI.

"Artificial intelligence is a good thing to follow in its own right," he says, "but the areas which the researchers have concentrated on are not necessarily germane to robotics. An expert system could very well tell you how to cope with all the arc welding problems that ever existed, for ex-

"You end up with a tremendous respect for a human being if you're a roboticist."

How different are robot senses from their human equivalents? Looking at human abilities in general, Engelberger says, "You end up with a tremendous respect for a human being if you're a roboticist." Regarding vision in particular, he makes his point, in his usual way, with an anecdote:

"I remember Asimov was on a program. Some woman says, 'I don't know what all this fuss is about trying to get vision in robots.' He says, 'Well, how do you think it works?' She says, 'Well, I assume in your head there's some sort of a little camera that's there and you get the television picture.' And he says, 'Yeah, but who's watching?' Bravo! So we've got to have a way to watch. We've got to be able to sense."

ample, and the robot could have it in its bag of tricks—maybe.

"Certainly an awful lot of artificial intelligence has been related to language and understanding. All that doesn't mean anything to a robot. You can come up with a robot language that is unambiguous to a robot. I recall someone in that business saying, it's a lot easier to deal with Japanese than it is with English. It's not nearly as ambiguous as English is for speaking to robots. So, great, you watch artificial intelligence and the expert systems in different arenas, and they may be significant. But they're not crucial to the robot, at least as far as I can tell."

TOWARD THE FACTORY OF THE FUTURE

Without question, the factory of the future will be designed to accommodate robots. But Engelberger emphasizes that other technologies will shape future manufacturing as well. "If you're in manufacturing," he declared as the keynote speaker at the chartering of a new Robotics International chapter, "you've got more riches before you than ever in history." Central to all those technologies are the computer and the system-level view of manufacturing.

"Probably the person to speak to that best would be Jim Albus at the National Bureau of Standards," Engelberger recommends, "because he's been hawking, and a lot of people have adopted the so-called hierarchy theory. You have a computer that works at the arm level. Then you have another that works at the task level. Then you have another one up higher than that, bringing all the different tasks together, each one at a higher echelon with a higher-order responsibility.

"Everyone's fighting networks today. Eventually, all the machine tools will talk to the net, and the robots will talk. In a lot of industries, aerospace, for example, it's going to be hard to pick out the robot. There will be some manipulation going on, but the robot will be distributed, with intelligence that will permeate the factory workplace. And we have to be able to talk up and talk down. The robot's got to be able to accept instructions from a supervisory computer. The sensory perception at the robot has got to be able to send signals up to the supervisory computer to let it know what's going on down there."

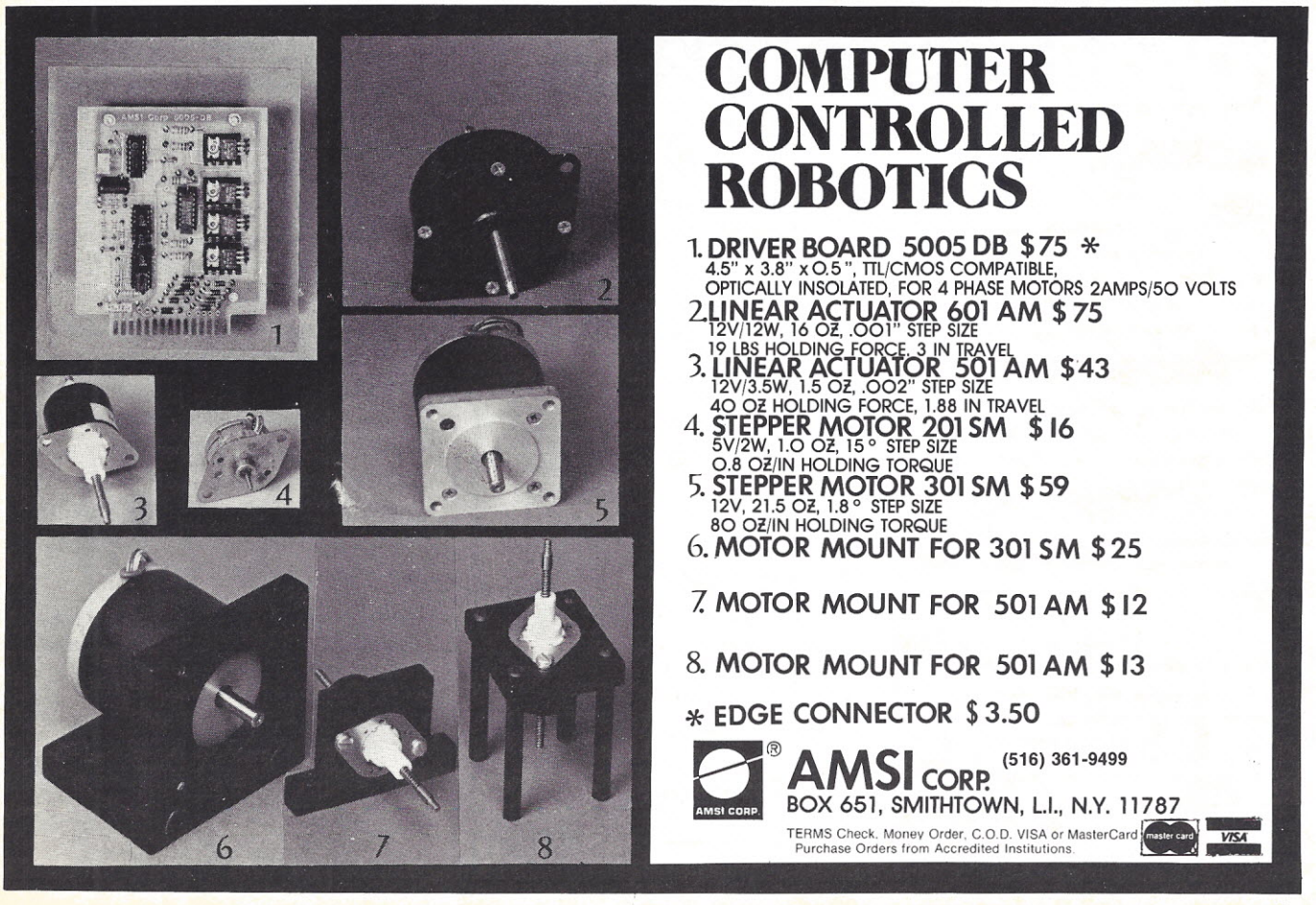
Engelberger predicts that those changes will take place less dramatically than some people think. He puts it this way: "There's turf that people in the factory are not going to give up. They're going to want to choose their own components. Therefore, you can't get away with the factory of the future quite that fast."

But Engelberger has no disagreement with the others on what technologies the factory of the future will have. Those are the "riches" he spoke of in his keynote speech. "You've got to consider computer-aided design [and computer-aided manufacturing]. You *must* consider group technology. You can't do group technology unless you've got factory data management. Only a computer can react fast enough to handle the inventory so that the flow goes through from raw stock to finished goods without any buffers. That's group technology's major benefit.

"Then you have automatic inspection, you have automatic warehousing. And in the warehouse, everything should be oriented. Integrating all those things will ultimately enable us to create our material wealth with the very minimum of human intervention. And it certainly won't all be robots."

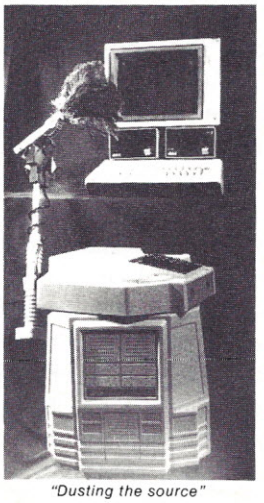
HARDWARE OR SOFTWARE?

As Engelberger said, the factory of the future certainly won't all be robots, and it



Circle 6

HERO ® / APPLE ® HANDSHAKE : $199.00!



"Dusting the source"

ROBI. . .an affordable interface for the robotics experimenter. Easy hook-up (8 screws on HERO ®, 1 card slot on Apple ® II or IIe) and a low price are combined with extra capabilities in the ROBI computer/ robot interface.

ROBI SPECIFICATIONS:

- *4 programmable, bidirectional, 8-bit ports for interface and expansion*
- *programmable control over handshaking*
- *access to signals through tie point blocks on robot's Experimental Board*
- *6-foot cable for interface, limited remote operation*
- *user-friendly software quickly transfers files between computer and robot; stores and retrieves files to and from disk*
- *not copy protected. Software is provided in DOS 3.3*
- *liberally commented source code included*

BERSEARCH
Information Services
26160 Edelweiss Circle
Evergreen, CO 80439
(303) 674-0796

APPLE ® is a trademark of Apple Computer
HERO ® is a trademark of Heath Electronics

VISA MasterCard

TOTAL CONTROL:

***FORTH:* FOR Z-80®, 8086, 68000, and IBM® PC**

Complies with the New 83-Standard

GRAPHICS • GAMES • COMMUNICATIONS • ROBOTICS
DATA ACQUISITION • PROCESS CONTROL

- ***FORTH*** programs are instantly portable across the four most popular microprocessors.
- ***FORTH*** is interactive and conversational, but 20 times faster than BASIC.
- ***FORTH*** programs are highly structured, modular, easy to maintain.
- ***FORTH*** affords direct control over all interrupts, memory locations, and i/o ports.
- ***FORTH*** allows full access to DOS files and functions.
- ***FORTH*** application programs can be compiled into turnkey COM files and distributed with no license fee.
- ***FORTH*** Cross Compilers are available for ROM'ed or disk based applications on most microprocessors.

Trademarks: IBM, International Business Machines Corp., CP/M, Digital Research Inc.; PC/Forth + and PC/GEN, Laboratory Microsystems, Inc.

FORTH Application Development Systems include interpreter / compiler with virtual memory management and multi-tasking, assembler, full screen editor, decompiler, utilities and 200 page manual. Standard random access files used for screen storage, extensions provided for access to all operating system functions.

Z-80 FORTH for CP/M® 2.2 or MP/M II, $100.00; **8080 FORTH** for CP/M 2.2 or MP/M II, $100.00; **8086 FORTH** for CP/M-86 or MS-DOS, $100.00; **PC/FORTH** for PC-DOS, CP/M-86, or CCPM, $100.00; **68000 FORTH** for CP/M-68K, $250.00.

FORTH + Systems are 32 bit implementations that allow creation of programs as large as 1 megabyte. The entire memory address space of the 68000 or 8086/88 is supported directly.

PC FORTH + ... $250.00
8086 FORTH + for CP/M-86 or MS-DOS $250.00
68000 FORTH + for CP/M-68K $400.00

Extension Packages available include: software floating point, cross compilers, INTEL 8087 support, AMD 9511 support, advanced color graphics, custom character sets, symbolic debugger, telecommunications, cross reference utility, B-tree file manager. *Write for brochure.*

VISA LMI MasterCard

Laboratory Microsystems Incorporated
Post Office Box 10430, Marina del Rey, CA 90295
Phone credit card orders to ***(213) 306-7412***

certainly won't all be computers, but it certainly will have plenty of computers, with intelligence distributed throughout the system. And computer intelligence is software.

In his speech to the new robotics chapter, Engelberger showed a cartoon of a robot crawling through the desert, gasping, "Software! Software!" Robots, he noted, have an insatiable appetite for software.

On the other hand, Engelberger thinks that software, in general, has been oversold. "I don't think the world is all software. The world is hardware. There are more people around who think that all I've got to do is write a better program and then the robot will be able to do a better job.

"But someplace or the other, you've got to interface with the real world. The physical interface is where the barrier is. The barrier right now isn't in software. The barrier isn't in VLSI; we have plenty of memory already. The barrier is we don't have a good sensory system."

Engelberger continued, "How do you replicate a prehensile hand? It boggles the imagination! I would much rather have someone come up with a clever way to make a prehensile hand than one more piece of software."

WANTED: PRAGMATIC DREAMERS

Joseph Engelberger envisioned an industry where others saw only fantasy. To do that, he had to be something of a dreamer. But he also understood that hard work and conviction can make dreams into reality. His dream came true because he was as much a pragmatist as a dreamer. He raised the money when no one believed.

Now, after a hugely successful career, he finds himself in much the same position as he was when Unimation began. He tells people that there will be practical, useful household robots by 1990. Many people say, "He's a dreamer," but Engelberger counters, "It's not as difficult a technical challenge as making an industrial robot was when we started in 1959."

Alfred B. Bortz is Assistant Director of the Magnetics Technology Center of Carnegie-Mellen University. He is also a freelance writer and consultant in the area of children's science books.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

71	81	91
Excellent	Good	Fair

Circle 13

THE LISTENERS: INTELLIGENT MACHINES WITH VOICE TECHNOLOGY

Patricia S. Restaino
Richard M. Melnicoff
VOTAN
4487 Technology Dr.
Fremont, CA 94538

With new technologies in voice input and output now on the market, a talking and listening intelligent machine should be a reality by the end of the decade. Verbal communication between man and machine is a very desirable attribute. It increases the quality of human interaction by partially or wholly eliminating keyboard data entry devices. In "busy eyes/busy hands" environments where writing and keyboard entry takes time away from the primary work task, voice technology can increase productivity. Training costs decrease because people can use voice commands to control robots or machines, instead of cumbersome keystroke or button-oriented command and control systems.

Voice Technology Defined. The entire field of voice technology can be broken down into voice input and voice output. As these names imply, voice input enables humans to communicate commands and data to machines by talking to them, and voice output technology enables these machines to talk back to humans with answers to questions, prompting information on what to do next, and so on. For voice input there are two major categories of technologies available: Continuous Speaker Dependent Recognition (CSDR), and Speaker Independent Recognition (SIR).

Voice Input. CSDR and SIR are two technologies by which speech may be recognized. CSDR recognizers recognize a particular individual's voice, basing the recognition on samples of speech that were previously entered. The use of speaker-dependent recognition in an application gives the system designer the ability to allow end users to define their own vocabulary. (Speaker-dependent recognition also offers the flexibility to train the system to recognize words in any language.) The newer continuous speaker-dependent recognition techniques permit communication with a robot or machine in a normal conversational manner. In the past, isolated or discrete recognition made it necessary to pause between words. CSDR eliminates the need for a pause and lets the speaker converse in full sentences, as in normal conversation.

Voice Output. Speech synthesis is the artificial reproduction of phonemes, the smallest sound units of a spoken language. To date, the tinny, mechanical, monotonal sounds are what we have accepted as the robotic or artificial-sounding voice.

Speech compression techniques, on the other hand, allow reconstruction of the human voice from coded digital information. Compressed human speech allows all the tone, inflection, feeling, and emphasis of the human voice to be retained. A robot or machine using compressed human speech has more natural interaction with its human operators.

Speech compression is used as a key technology in response and voice store and forward applications. Voice recording, using compressed data, is the practical method of recording a human voice for later playback as a prompt or question. A recorded voice message can easily be sent as digital data lines, i.e. forwarded.

Technological Considerations. Accuracy and robustness are terms that refer to how a recognizer performs given environmental changes. Accuracy is defined as the measure of how often a recognizer correctly understands an utterance. Robustness is the ability of the recognizer to operate effectively under adverse conditions such as background noise, changing inflections, and speed of speech. Recently systems with a high degree of accuracy and robustness have started to appear in the marketplace at quite reasonable prices.

The Integrated Solution. The VOTAN voice-response and speech-recognition systems provide an integrated combination. VOTAN's development of a proprietary transform was a significant breakthrough. The new transform provides a balance between cost, noise immunity, and calculation speed, while offering voice recognition and voice output on the same hardware.

Humans typically think of the input from a microphone as a time-domain signal: a voltage level which changes over time. The primary function of a voice-recognition transform is to convert the voice signal from the time domain to the frequency domain. The VOTAN transform yields 128 spectral coefficients in the system's passband (0–4 KHz). The straightforward transform calculations exceed real-time requirements by a significant factor. In order to reduce real-time requirements, VOTAN

has developed a transform which is done without multiplications. Other computational requirements are also reduced.

Another way to analyze voice input for recognition has been to use analog filter banks. The digital transformation or calculation approach has one main advantage over the analog filter bank as a method of generating spectral coefficients. No precision analog filter components are required, thus reducing manufacturing costs while enhancing the number of coefficients available.

The particular digital transform used by VOTAN also provides a voice-response capability. This is not readily obtainable with analog filter banks. The transform is invertible, so frequency-domain spectral data can be reconverted to time-domain audio signal data. The benefit of using the symmetric (invertible) transform is that the same system can be used to encode and decode messages, providing a voice-messaging capability.

Evaluating Voice I/O Equipment. Accepting the fact that voice I/O is state-of-the-art technology, what are the criteria for evaluating voice products for consideration in automated machinery and other robotic applications? Performance, cost, ease of development, and ease of use, seem to be the most pertinent areas.

Recognition Performance. Key factors in evaluating performance are recognition accuracy, noise immunity, and quality of speech output. With the recognizers available today, one should expect greater than 95 percent accuracy in the environment where the robot or machinery will be used. Ninety-five percent accuracy means that one message in 20 will be misidentified on the first attempt.

Applications on factory floors where the noise level easily exceeds 75 db, or offices where the average noise level is in excess of 50 db, test a recognizer's ability to perform with accuracy greater than 95 percent.

Output Quality. Application of voice output must balance bit rates and storage requirements against the quality of speech generated. The higher the bit rate, the higher the quality of voice output, but storage costs also increase. In many cases, if the application requires natural human-sounding speech, the added cost of the storage is easily justified.

Integrated Technologies. The advantages and savings of integrated technologies with shared resources have often been apparent when both recognition and output are required. Acquiring voice equipment that offers recognition, response, and telephone capabilities in one system can save system costs because the system uses common hardware for several purposes. Integrated technologies also make overall system integration simpler, by reducing the number of boxes and connections required. If there is only a limited amount of physical space available, integrating all voice functions on one board or in one box can make a lot of sense.

Ease of software development should be a key feature in selection of a voice system. Flexibility of the software is an important consideration provided by development aids and utilities. Integrating speech input and output into an application should be done with ease. The ability to establish and change the vocabulary using utilities provided should be a relatively trivial task. Programming and recording and/or updating output messages should be convenient and readily accessible to the system programmer.

Overall, a good suite of software tools provides the flexibility necessary to create a custom application.

Microphones and Other Sources of Input. Input devices are numerous and should be interchangeable when necessary. Telephone, many varieties of microphones, or radio transmitters are the most frequently used input alternatives in industrial use of voice recognition at present. All these options may be employed at one time or another in the course of developing and using an application.

Once an application has been developed, the most important aspect is the human interface. It is imperative when evaluating voice hardware that the following questions be answered:

- How many times does the person who is using the system have to repeat each vocabulary word?
- How often does the entire vocabulary need to be retrained?
- How difficult is it to train the system?
- What happens to the recognition accuracy when the environment or conditions surrounding the application change?
- Is the voice output tolerable or appropriate for the application?
- Can the equipment be trained in any language?

Answers to these questions provide information that should be taken into account when making that initial investment in a voice system.

Industrial Use of Voice Technology. In a "busy eyes/busy hands" environment such as a factory or laboratory, where workers must use hands and eyes simultaneously, voice offers many benefits. Workers are able to emphasize their primary tasks, and use their voices to enter data rather than stopping to enter information on a keyboard. This advantage alone can increase productivity.

Historically, voice input has also increased accuracy and throughput. Training is reduced, as users can use their voices and not be intimidated by a keyboard, mouse, or unfamiliar software.

Human interaction with robots or machines in any environment can be greatly simplified. Workers can direct robots verbally while performing other tasks. As voice I/O systems advance, more and more uses for robots will be found in a variety of environments.

As can be seen, combining the newest technologies of voice input and output provides the features to create a more versatile and humanlike robot. Continuous Speaker Dependent Recognition gives the intelligent machine a viable, real-time input of commands. Voice response lets the machine give feedback verbally.

Voice technology has been offered in bits and pieces in the past. Fragmented solutions, often expensive and of poor quality, have to date been what was available from the voice industry. The recent arrival of integrated packages has reduced cost, improved quality, and combined input and output technologies on a single electronic module. These advances have proven that voice is a viable, cost-effective alternative to communicating with an intelligent machine, in real applications.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

72	82	92
Excellent	Good	Fair

FORTH FOR COMPUTER VISION IN INDUSTRIAL APPLICATIONS

John E. Lecky
Control Automation, Inc.
Princeton-Windsor Industrial Park
PO Box 2304
Princeton, NJ 08540

WHAT IS COMPUTER VISION?

This article deals with the programming language FORTH as applied to computer vision uses. The application discussed is a real machine which has been completely developed in FORTH and is in production. Advantages to FORTH I discovered in the development also will be discussed.

Any article on the subject of computer vision must begin with a clarification of terms. "Computer vision" is a general term, often misused or misinterpreted.

A video camera, when coupled to a computer which has been equipped with hardware that enables it to read that camera, creates a "vision computer." The camera is equipped with standard lenses and filters and provided with a mounting bracket and light source to create a desired image of an object. The camera converts the image that it sees into a video signal exactly like those found in an ordinary black and white television. The computer then uses its special hardware to digitize that image, converting it to discrete number values representing the light intensity of each picture element, or pixel. A value of zero indicates that the camera sees no light coming from that particular region. If the camera barely senses light in a region, the pixel values for that area will be 1.

As more light is sensed, the pixel value increases until that pixel value of the camera becomes saturated with light, unable to measure any additional increase in brightness. The pixel value for this light level depends on the precision of the analog-to-digital conversion hardware in the computer and is typically 63, 127, or 255 for 6-, 7- or 8-bit precision, respectively. For most purposes, dividing the sensitivity range of the camera into 64 different brightness levels, or "gray levels," is more than adequate, since a variation in light intensity of less than 5 percent of the range of the camera is seldom meaningful. At any rate, for repeatable industrial performance the variation must be gross, around 30 percent of the range of the camera, indicating that dividing the response of the camera into only ten or so gray levels would be adequate. For this reason, the most commonly used gray scale runs from 0 to 63.

After conversion to their digital values, the pixels are automatically loaded into the computer's memory as a large two-dimensional array. Processing a video image consists of nothing more than interpreting this massive data array. All software operations are standard; for example, to find the overall brightness level seen by the camera, one needs only to compute the average value of all the elements in the array. The "magic" in computer vision, if indeed there is any, lies only in the way one processes large data arrays to extract useful information.

BACKGROUND

I work as a vision systems engineer for Control Automation, Inc., a Princeton, NJ, company concentrating on turnkey robotic assembly and inspection systems for the printed circuit board manufacturing industry. Recently I've played a major role in the development of a turnkey system, the InterScan 1500, used to inspect the underside of PCBs to determine whether leads have been properly inserted through holes. This system uses four CCD cameras and a custom system controller produced by Control Automation, the InterVision 2000, to perform the inspection and overall system control tasks.

The cameras are mounted to provide redundant inspection from different angles of a two inch square region of the PCB. They are moved beneath the entire board area by an X-Y scanning assembly. PCBs can be loaded into and unloaded from the machine by a custom board transport system, allowing the machine to be integrated directly into the assembly line. Photo 1 shows an overall layout of this machine.

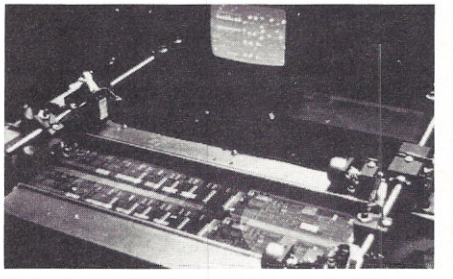


Photo 1. The InterScan 1500 product of Control Automation shown here had key software components developed using the interactive environment of FORTH.

The InterVision 2000 System Controller employs an Intel 8086 based single-board computer. The production level system is equipped with a 3.5 in. hard shell floppy disk drive, a 10 Mbyte Winchester hard disk, a video display monitor, and a "micromouse" editing pendant. The system has 128 Kbyte RAM standard, and is readily expandable to 640 Kbytes. The operating system, development system, and vision algorithms are all written in FORTH, a primary advantage that will be the major focus of this article. Some time-critical routines have been rewritten in assembly language.

All operation is menu driven, with single keystrokes carrying out most desired operations. No programming of any kind is required of the operator at any stage of operation. Specific data regarding the style

of the PCB and the location of the leads is generated through an automated process, with simple editing functions being the only requirement made on the human operator. Alternatively, the data can be downloaded from a CAD database. The machine is currently in volume production.

THE REALITIES OF INDUSTRY AND VISION SOFTWARE

The rigors of industrial applications dictate that software be designed and implemented to leave nothing to chance. Most end users of industrial software, especially those working on the factory floor with expensive equipment used in volume production, are computer illiterate and mechanically uninclined. Software, just like hardware, is misused in every possible way. All sorts of invalid input is entered, power up and down sequences are thrown away or rewritten, storage media is abused, and inefficient operating procedures followed. Nevertheless, the customer expects a machine that always works, doesn't lose data, doesn't confuse operators, and, most of all, performs the job required in a way that seems (at least to the operators) easy and straightforward—sometimes even fun.

In vision applications, especially in research and small industrial companies, software generation is a day-to-day, even hour-to-hour, occurrence. Algorithms tend to be developed empirically. Thresholds, gains, and other inputs that may be dependent upon lighting or material variations must be automatically computed through the use of some algorithm. Inspection machines, such as the InterScan 1500, must be given some notion of the difference between good and bad.

One of the most useful vision algorithms is the gray average, which computes the average value a pixel takes on over a certain area. Another algorithm, equally widely known but more useful, is a variation of the gray average—a simple weighting, or moment, is added in for each gray level, based on its distance from some base pixel value. This essentially amplifies the impact of very bright or very dark pixels. A third common algorithm is the template match, a "snapshot" technique in which a reference image is stored away and compared, pixel by pixel, to the current image.

Other algorithms include convolutions and filters, commonly used for smoothing and feature detection. Connectivity analysis, used on the InterScan 1500 to provide automatic teaching capability (the machine looks at a new board, finds all the leads, and stores away their locations) is simple to implement. Each pixel is examined and, if it is above a certain brightness, grouped with its bright neighbors. In this way, contiguous "blobs" are identified. Any operation that has classically been applied to a data array can be applied to an array of pixel values, sometimes producing useful information and sometimes not.

Industrial applications usually require moderately fast, relatively fault-tolerant algorithms. These algorithms must be extremely stable, reliable, and repeatable to be of any use on a production floor. The InterScan 1500, for example, must be tolerant of variations in the diameter, length, and position of the leads; a snapshot technique would not work here. The algorithms used in industrial machines are highly specialized, and development continues far past the prototype stage, usually over the course of several months at customer sites. Literally hundreds of algorithms and variations must be conceived, implemented, and tested to arrive at the final version.

The time from conception to market and the differences between your machine and the competition's are important. Enhancements must be quickly implemented, and bugs corrected immediately. These considerations dictate the choice of a programming language. The software written for a machine like the InterScan 1500 is complex; 500 Kbytes of source program is not uncommon. A program of this size must be readable, maintainable, and easy to enhance. Above all, the program must perform properly and quickly. We concluded early in our design activities that FORTH would be an exceptionally good choice for industrial vision applications.

THE ADVANTAGES OF FORTH

FORTH has been the subject of controversy. It has been said that FORTH, by its very nature, is "unreadable" and therefore difficult to maintain. But any language, FORTH included, can be used in such a way that only the original programmer can read the code, producing what is traditionally referred to as "unreadable" code. In time, even the original programmer can forget how the code works, and the software becomes useless should it ever need to be modified.

The following are three examples of a program designed to scan through a 10 by 10 array called PIXEL_ARRAY and compute its average element value. This routine could be used to take a gray level average over a region of a pixel data array. The three programs were written to do the same thing, but written in different styles. The first shows code with readability maximized, sacrificing some speed performance. The second shows code sacrificing no speed, and also written to be readable by any competent programmer. The last example is written to be functional, but inefficient and totally unreadable. Each example has been programmed first in C, for comparison, and then in FORTH.

Programming in Two Languages:

Example 1: Most readable

```
C:

int gray_average()
{
  int i,j ;
  int sum = 0 ;
  int avg ;

  for (i = 0; i < 10 ; i++)
    for (j = 0; j < 10; j ++)
      sum + = PIXEL_ARRAY [i][j] ;
  avg = sum / (10 * 10) ;
  return (avg) ;
}

FORTH:
VARIABLE SUM
: GRAY_AVERAGE (--n)
  0 SUM !
  10 0 DO
    10 0 DO
      PIXEL_ARRAY I + J 10 * + @ SUM+!
    LOOP
LOOP
SUM @ 100 / ;
```

Example 2: Fairly readable, faster execution

```
C:
int gray_average ()
{
  int i ;
  int sum = 0 ;
  int *pixel ;
  pixel - PIXEL_ARRAY ;
  for (i = 0; i < 100; i++)
    sum += *pixel++ ;
  return (sum / 100) ;
}
```

```
FORTH: :
: GRAY_AVERAGE ( )
  0
  100 0 DO
    PIXEL_ARRAY I + @ +
  LOOP
  100 / ;
```

Example 3: Unreadable but functional

```
C:
gray_average(){int i,j;int sum=0;for(i
=0;i<10;i++)for(j=0;j<10;j++)sum
+=PIXEL_ARRAY[i][j];return(sum/100
);}

FORTH:
: GRAY-AVERAGE 0 100 0 DO PIXEL_ARRAY I
+ @ + LOOP 100 / ;
```

These examples illustrate the basic difference between readable and unreadable software. Programming languages are not in themselves inherently readable or unreadable. In my opinion, poorly written C is much less readable than FORTH, mainly because more written code is almost always required in such a language to accomplish a desired goal. It is the programmer, not the language, who creates unreadable programs.

FORTH has other virtues as well. Every structure a classical programming language allows is available in FORTH. If, else, do while, until, for, cases, and other structured decision-making and branching commands are available in like form and perfectly adaptable to day-to-day applications. FORTH is highly modular and interactive. Each module is complete and stands alone. Unlike other languages' formal and sometimes complex parameter linkages for modules, FORTH parameters are always passed on a stack, and results are returned on the same stack. This arrangement is both simple and completely general purpose.

Another advantage of FORTH over classical programming languages is the basic development process. To test the C routines listed above, a second routine, main, had to be written that would initialize the array, call the gray_average routine, and then print out the results. In FORTH, the array was created and initialized once, after which it became a part of the "dictionary." The FORTH routines were typed interactively, and testing them required only typing their names and examining the number left on the stack. This interactiveness is the key advantage of using FORTH in software development.

In C, the process was more tedious. First, the main routine had to be compiled; then the gray_average routine had to be compiled. Finally, the two had to be linked to make a working program. Only then could anything be executed. The overall development cycle for C typically takes several times longer than the equivalent cycle in FORTH.

Another of FORTH's assets is that it is in itself the operating system and occupies a very small space, typically 10 to 20 Kbytes of memory, depending on the additional features placed therein. As FORTH is a compact interpretive language, each byte stored has a high semantic content. This, together with the fact that FORTH code is extremely compact, means the small vision computer typically found in industrial vision equipment is also the development system. No mainframe is required to compile the program; the small vision system is more than capable of doing it, especially since FORTH compiles faster than the source can be read from disk. The time to completely reload the half megabyte of source code running the InterScan 1500 is under two minutes.

The modularity speeds development as well. The entire program often does not need to be loaded, especially if testing of one or two new definitions is being done. The time to load three or four thousand bytes of source code and be ready to execute it might be about one second. No separate compiling, linking or downloading steps are ever required.

This means two things: first, much higher productivity, since the programmer is always working with the target system, enabling him or her to see the results of a software change literally within a few seconds of its having left the editor; second and more important, changes can be made to the operating software in the field.

As noted earlier, competition being what it is in high technology industries like computer vision, customers constantly make comparisons between one machine and another. Getting an algorithmic improvement or bug fix to them may be the key to their continuing relationship with your company. With so few obstacles standing in the way of software repair and enhancement, it is possible in FORTH to improve software much more quickly. In fact, with the ability to modify software available to anyone with a piece of FORTH-based equipment, it is not unheard of to talk a

THE fifth generation language

P R O L O G

Implementing the full Edinburgh Syntax as described by Clockson and Mellish.

Recognized by Japan as providing unparalleled opportunity for artificial intelligence.

Applications:

- The highest level of a hierarchial robotic control system.
- Machine recognition of natural language.
- Expert systems and knowledge engineering.

Optional:

- Virtual memory
- Special libraries
- Language extensions
- Large model

educational package

$29.95

•other versions *$100- $500*

Requires 192K memory and runs under MSDOS and PCDOS versions 2.0 and later.

automata design assoc.

1570 Arran Way, Dresher, PA 19025

Technical: (215) 646-4894

Orders: (215) 355-5400

Visa, Mastercard, Am Ex

Advertising

R.S. No. Company

1 AMSI Corp., p. 21
2 American Design Components, Cov. II
3 Arctec Systems, Cov. IV
4 Astrotronics Microsystems, p. 7
5 Automata Design Assoc., p. 27
6 Bersearch Information Services, p. 22
7 Centroid, p. 32
8 Electronic Systems and Instruments, p. 10
9 ForSight, Inc., p. 8
10 Industrial Magnetics, Inc., p. 10
11 Intrinsic Technologies, Inc., p. 32
12 John Wiley & Sons, p. 8
13 Laboratory Microsystems, Inc., p. 22
14 Light Machines Corp., p. 35
24 Marcraft Int'l, Cov. III
15 Micron Technology, Inc., p. 7
16 Northwest Computer Algorithms, p. 9
17 Prism Robotics, Inc., p. 19
18 Real Time Logic, p. 18
19 Rio Grande Robotics, p. 9
20 Robots 9, p. 5
* Robotics Age Back Issues, Insert
21 Skye Products, p. 3
22 Solution Systems, p. 28
23 Vernitech, p. 28

**Correspond directly with company*

customer through editing his own copy of the program over the telephone in circumstances where unforseen bugs arise and overnight carrier is not fast enough.

Like other languages, if interpretive execution is too slow, FORTH has the capability of rewriting critical routines in assembly language at any time. A working program may be created quickly and easily using FORTH, and then improved by rewriting in assembly language those modules whose execution speed is extremely critical. Unlike many less interactive languages, most FORTH implementations provide an easily accessible built-in assembler to facilitate such assembly language optimization. These modules need be rewritten only one at a time, so a working version of the complete program is always available. This makes unnecessary a complete reprogramming merely to speed up a few sections of the software.

In sum, FORTH proves an extremely practical vehicle for the creation of industrial robot vision equipment. FORTH is readable and therefore maintainable if written with proper structure the way traditional languages commonly are. FORTH is compact, allowing it to be placed in its entirety on small, product level microcomputers. This means no mainframe or other development system is required. FORTH programming is time effective, since programmers can develop, load, and test their code in a loop much tighter than that available with traditional languages.

FORTH is fast, much faster than regular interpreted languages, and also allows an assembler easy access to the fastest possible language for those modules whose execution time is critical. FORTH is versatile and adaptable to many environments, as current FORTH publications are beginning to show. FORTH allows the creation of highly customized and sophisticated data structures and syntaxes, easing programming effort and enhancing program readability.

CONCLUSION

FORTH is a highly productive language in which to create complex, rapidly changing industrial equipment. But the only way to believe FORTH is to try it. It is a language which, like other languages, can be misused, but when used properly it is a highly readable, enjoyable language in which to program. The way to use FORTH to its utmost has been fully described in Leo Brodie's book, *Thinking FORTH,* (Prentice Hall, 1984.) The book covers all elements of FORTH: philosophy, design, style and documentation, and advanced concepts. The preface to the book, for those as yet unacquainted with FORTH, is Brodie's earlier book, *Starting FORTH,* (Prentice Hall, 1982.) The two books as a set form the FORTH "bible."

My background includes BASIC, PL/I, COBOL, C, LISP, ETA, PASCAL, FORTRAN, and a handful of assembly languages in addition to FORTH. At Control Automation we have proven to ourselves that FORTH is far superior for the work that we do because of its development time advantage and the other advantages discussed above. It is my hope that others will try the language for their real-world applications and find it an equally perfect match.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

73	83	93
Excellent	Good	Fair

PROLOG-86™

Become Familiar in One Evening

Thorough tutorials are designed to help learn the PROLOG language quickly. The interactive PROLOG-86 Interpreter gives immediate feedback. In a few hours you will begin to feel comfortable with it. In a few days you are likely to know enough to modify some of the more sophisticated sample programs.

Sample Programs are Included like:

- **an EXPERT SYSTEM**
- **a NATURAL LANGUAGE INTERFACE** (it generates a dBASE II "DISPLAY" command)
- **a GAME** (it takes less than 1 page of PROLOG-86)

PROTOTYPE Ideas and Applications QUICKLY

1 or 2 pages of PROLOG is often equivalent to 10 or 15 pages in "C" or PASCAL. It is a different way of thinking.

Describe the FACTS and RULES without concern for what the computer will have to do. Maybe you will rewrite in another programming language when you are done.

Programming Experience is not required but a logical mind is. PROLOG-86 supports the de facto STANDARD established in "Programming in Prolog."

CONTEST: Win $1,000. Ask about it. Deadline of 4/30/85.

AVAILABILITY: PROLOG-86 runs on MSDOS, PCDOS, IBM AT or CPM-86 machines. We provide most formats. The price of PROLOG-86 is **only $125.**

Full Refund if not satisfied during first 30 days.

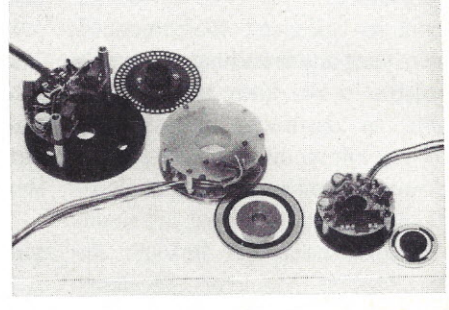
800-821-2492

Solution Systems™

335-R Washington Street
Norwell, MA 02061

617-659-1571

Circle 22



KIT ENCODERS THAT REALLY SAVE YOU MONEY.

Most kit encoders are so tricky to align that they end up costing you more in labor than they save.

Not so Vernitech kit encoders.

Our special design comes with alignment tools and a simple set of instructions. It is so easy for *anybody* to assemble perfectly. The original low cost of our encoder plus the reduced cost of your "in-house" assembly will result in greatly reduced total cost. Buying Vernitech kit encoders can save as much as 50%!

Call or write

VERNITECH

a division of Vernitron Corporation

300 Marcus Boulevard, Deer Park, N.Y. 11729
(516) 586-5100 / TWX 510-227-6079

Circle 23

A SECOND-GENERATION AUTONOMOUS SENTRY ROBOT

H. R. Everett
8414 Danford Court
Springfield, VA 22152

The prototype robot, ROBART II, is a sophisticated multisensor platform employing a control hierarchy of nine microprocessors, and intended as a testbed for AI research in the fields of autonomous navigation and collision avoidance. ROBART II is a second-generation machine built to improve some of the capabilities of its predecessor ROBART I, a mobile autonomous sentry (see "A Computer Controlled Sentry Robot," *Robotics Age*, Mar/Apr '82).

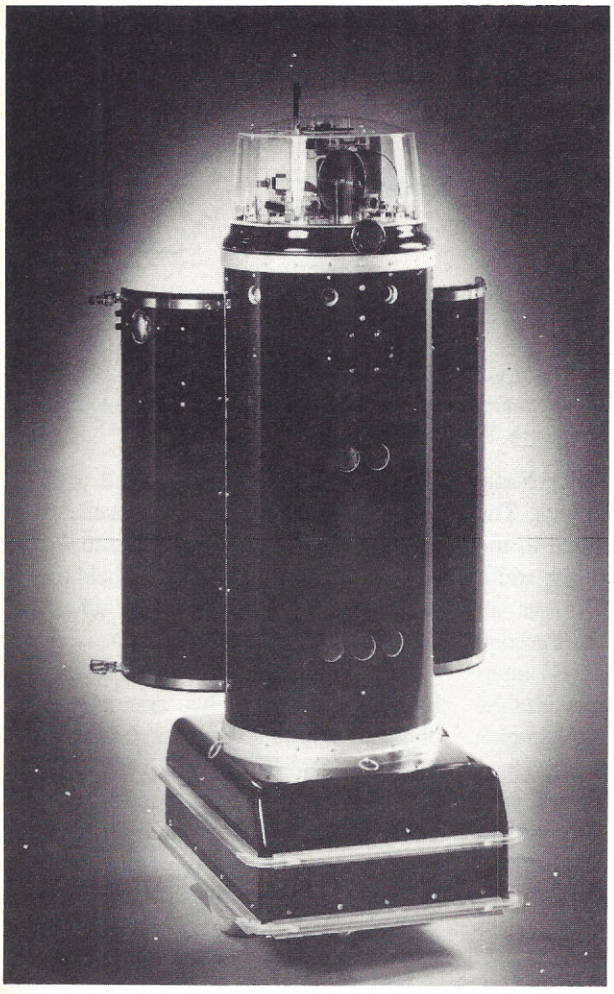


Photo 1. This front view of the prototype robot ROBART II shows the five element ultrasonic sensor array. The upper body case is fabricated from a section of 12 in. plastic irrigation pipe and attaches to the base with four quick-release pins. The parabolic reflector for the long-range near-infrared proximity detector is visible under the plexiglass dome. The photo is courtesy of the Naval Surface Weapons Center.

This second prototype uses the same software development system as the original ROBART I and employs a single-board 6502-based microcomputer, designated as CPU #1, configured as the "Scheduler." Below this level in the hierarchy, however, is another layer of five 6502-based systems functioning as dedicated controllers. These microprocessors are assigned functions associated with speech, steering and drive, ultrasonic ranging, head motion, and vision. They are interfaced to the Scheduler through an 8-bit parallel bus and a multiplexed RS-232 serial port. A special in-circuit-emulator allows for these stand-alone controllers to be mapped into the address space of the Scheduler during software development and debugging, after which the resultant code is burned onto an EPROM and made resident on the individual boards themselves. This greatly simplifies the process of fine tuning software that interacts with programs running on a separate machine in the network, in that both machines can be brought up and made to run simultaneously in the development mode. Changes can be made as needed with no need to burn an EPROM until both sets of code have been perfected. At the very bottom layer in the hierarchy are two additional microprocessors, assigned respectively the responsibilities for speech synthesis and recognition.

Another very significant difference between the two prototypes is the addition of the "Planner" at the very top of the hierarchy in ROBART II. This 16-bit machine provides a home for the actual intelligence of the system. Research in this area is currently being conducted by Ms. Anita Flynn of the Artificial Intelligence Laboratory at MIT, using initially a radio link between the Scheduler on the robot and an IBM XT located some distance away. A single-board machine will eventually be installed on the robot to execute the code now being developed.

Only marginal performance was ever obtained from the single forward-looking ultrasonic ranging unit on ROBART I, and maximum range under optimum conditions was only about ten feet. In contrast, ROBART II has installed seven Polaroid ultrasonic ranging units, with five transducers mounted in a sequentially fired array centered on the forward axis. (See Photo 1.) This array configuration allows for beam splitting techniques to be employed to increase the horizontal resolution of the system, and to provide course and speed corrections for following a moving target while remaining a specified distance away. In this mode the robot's mean forward velocity is calculated as a function of distance to the target. A slight differential between left and right drive motor speeds is introduced as a function of how far off the array centerline the target appears. This results in the platform turning toward the target being followed, until the target is dead ahead, without the necessity of mechanically panning a single sensor back and forth to ascertain the target's relative position.

The remaining two ultrasonic sensors, mounted on the head, can rotate in turn up to 100 degrees either side of centerline. A dedicated 6502-based controller, CPU #3, performs all tasks associated with ultrasonic ranging. An 8-bit command from the Scheduler tells CPU #3 which

sonars to fire; these units are sequentially enabled, and the time required for each to detect an echo is converted to distance and stored. Upon completion of the full sequence, CPU #3 requests permission to transmit the range information up the hierarchy and, when acknowledged, passes it to the Scheduler. The sequence is then repeated until altered upon command from the Scheduler. The incoming ranges are read in by an interrupt routine and stored in the Scheduler's Page Zero for use by any routines that need range information from any of the sensors. The sonar drivers themselves are interfaced to CPU #3 through a three-channel eight-input multiplexer. All time-to-distance conversions are done in software by CPU #3.

ROBART II also features a vastly improved mechanical design. The entire electronics package visible through the rear access doors is easily removed by loosening two retaining screws. All connections to the robot are made through numerous ribbon cables terminating in zero-insertion-force (ZIF) DIP sockets. The upper body separates from the fiberglass base unit for transportability and maintenance, and is held in place by four quick-release pins as shown in Figures 2 and 3.

The propulsion system uses two individually controlled drive wheels, one on either side of the base, with casters in front and rear for stability. This configuration allows the robot to spin in place about its vertical axis for markedly improved maneuverability. ROBART I employed a tricycle wheelbase with a steerable, driven front wheel which resulted in a much larger turn radius and poor maneuverability, but which offered better performance with regard to climbing over small obstructions. The small diameter casters on ROBART II are suitable only for indoor use, unable to surmount surface discontinuities greater than about one inch. The forward caster "floats" up and down attached to a spring-loaded shock absorber which keeps it in contact with the floor when traversing non-planar surfaces. Note that this is not a concern with a three-point platform.

The drive motors used on ROBART II are independently controlled through pulse width modulation (PWM), and synchronized by high-resolution optical encoders attached to the armature shafts. The optical encoders supply precise displacement and velocity information for use in dead reckoning during maneuvering. A dedicated 6502-based controller handles all drive and steering control functions as directed by the Scheduler. Pulse width modulation is implemented through special hardware resident on an interface card connected between CPU #4 and the power transistors controlling the motors.

undesirable conditions detected by these sensors will cause the drive to be immediately disabled; the Scheduler is alerted as to which corner sensor detected the problem. The Scheduler then asks for help from the Planner and re-enables the drive if a high-confidence solution can be

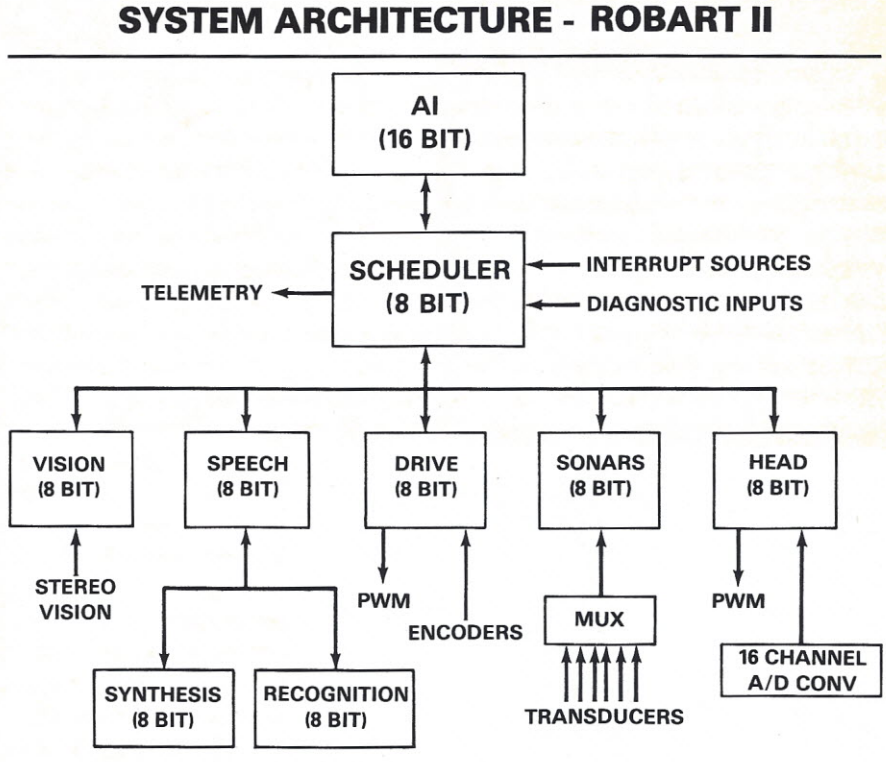


Figure 1. A network of nine microprocessors make up the control hierarchy for ROBART II, seven of which have been installed and tested to date. The dedicated 6502-based controllers at the intermediate level are all CMOS, with a current consumption of only 35 mA each.

For each motor there exists a directional control line and an on/off control line. The on/off control lines are connected to the outputs of the left and right pulse width modulators. The width of the pulses appearing on these outputs is set by the commands from CPU #4 to the PWM interface card, and determines the speeds of the respective motors. Conventional eight-inch wheelchair tires and motors provide a quiet, powerful propulsion system with minimal wheel slippage. Decoupling clutches on each wheel allow for "free-wheeling" the robot around when the system is shut down.

A converging-type near-infrared proximity sensor is installed on each corner of the base of the unit, positioned so as to detect the presence of the floor. This precludes falls down stairways or other attempts to traverse unsuitable discontinuities that could entrap or even damage the unit. Any found. If not, speech synthesis is used to request human assistance. This same drive circuitry can be deactivated manually by an observer using a small hand-held transmitter similar to a garage door opener if so desired for safety or other reasons.

The only tactile sensors employed on ROBART II are the two circumferential bumpers around the base unit. Each consists of a free-floating plastic strip encased in a fixed housing, spring loaded so as to normally be in the extended position. A series of microswitches is arranged behind these strips in such a fashion that they are activated by any displacement of the strip. When the bumper comes in contact with another surface, the floating strip is locally depressed and in turn activates the appropriate microswitch to provide geometric resolution of the point of impact. Intelligent recovery is facilitated by the collision-avoidance software.

The most significant component of this continuous bumper design is the corner piece, designed with an angled cut at both ends so as to mate with the floating strips in the linear casings. When a corner comes in contact with another surface, it will press against a floating strip and cause it in turn to activate the microswitch nearest the corner. The angled construction also permits lateral motion of the strips within their casings when responding to oblique impacts, and is the key to the continuous yet collapsible floating design. The configuration doubles as a protective bumper for the surface of the robot base and any noncontact sensors mounted thereon.

The most useful navigational information available to ROBART I came from a long-range near-infrared proximity sensor mounted on the head with a maximum detection range of six to seven feet. A much improved version is employed on ROBART II, which provides for ranges up to 18 feet, variable threshold detection, and a programmable array of four high-power LED emitters. This sensor is used to complement the sonar range information from the head-mounted transducers when collecting data on the robot's surroundings.

Two other types of near-infrared detectors are used by ROBART II. Three medium-range multibeam proximity detectors (Banner CX1-6) are arranged in a forward-looking horizontal array for collision-avoidance purposes. These modulated-beam sensor units have adjustable maximum ranges, set for this application to about five feet. They provide extended protection capability in the direction of travel, and collectively can discern if an obstruction is directly ahead, or to the right or left of centerline. These sensors serve as complementary backup to the five-element sonar array.

The final type of near-infrared unit is a short-range proximity sensor employing a pulsed output from a pair of high-power LEDs. A differentiating receiver/amplifier drives a two-channel threshold detector, with adjustable thresholds set to indicate target detection at 30 in. on one channel, and 18 in. for the other channel. Thirty-five of these are planned for eventual installation on the robot, appropriately situated so as to provide a protective envelope totally surrounding the unit. Outputs will generate interrupts to alert the Scheduler that a collision is imminent; the robot's course will be altered accordingly. Preliminary tests have been completed on a prototype of this sensor, and final design modifications are now being made prior to circuit board layout and construction.

Another dedicated controller in the hierarchy, CPU #5, is assigned all functions related to speech input and output. Below it in the hierarchy are CPU #7, a DT1050 speech synthesizer, and a soon-to-be-installed 6502-based speech-recognition unit which can recognize up to 256 words or phrases. Figure 2 shows the physical location of CPU #5 and the actual speech synthesizer, CPU #7.

A final 6502-based system is employed as a controller and signal processor for a stereoscopic vision system currently under development. To minimize processing requirements, this system employs two 256-element linear CCD arrays located in separate camera assemblies to be mounted on the head. Outputs from both cameras will be compared to ascertain distances to prominent vertical features using standard stereo ranging techniques. The excellent angular resolution afforded by an optical system of this type as well as the range information obtained will be used to augment data taken by the head-mounted sonar transducers for room mapping and collision-avoidance routines run by the Planner. In addition, the cameras will be used to locate and establish the range to a near-infrared beacon mounted on top of a stand-alone charging station which allows the robot to home in and make a connection for recharging its batteries.

ROBART II is equipped with a multitude of sensors for environmental awareness to support its role as an intelligent sentry robot. Special sensors monitor both system and room temperature, relative humidity, barometric pressure, ambient light and noise levels, toxic gas, smoke, and fire. In-

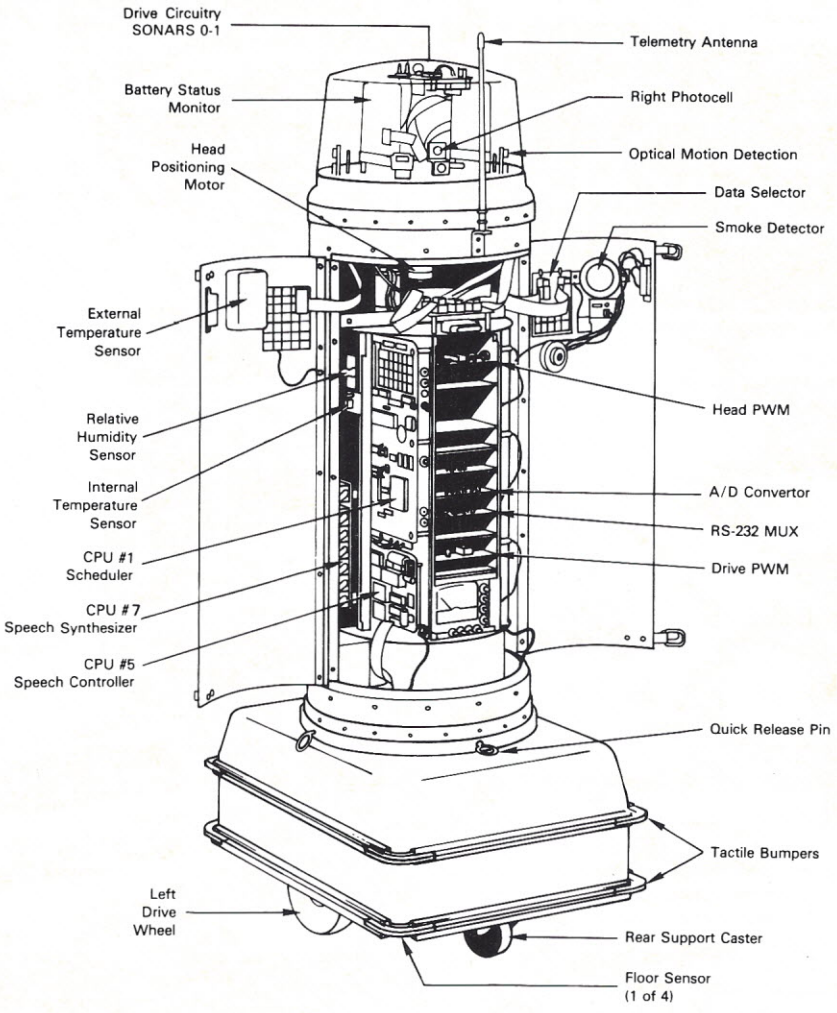
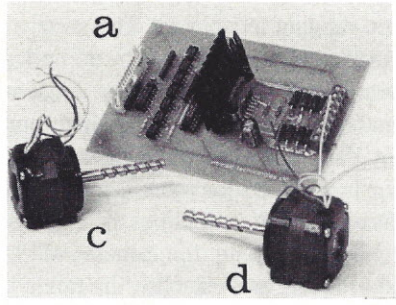


Figure 2. This left rear view depicts the location of numerous components. Near-infrared convergent-type floor sensors are located at each corner of the base shroud.

Circle 11



PERFORMANCE AND VERSATILITY

Stepper Motor Drivers and Motors from Intrinsic Technologies

a) Stepper Motor Driver: bipolar, unipolar, chopper or L/R, up to 2 Amps per phase. Optically isolated. Speeds up to 25,000 steps/second.
IT-01A.....$90

b) Dual version of above (not shown)
IT-02A.....$130

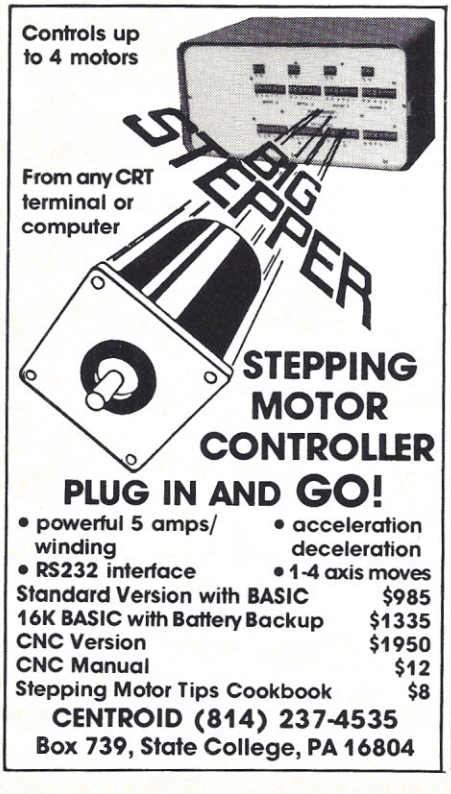
c) PM hybrid step motor, 3.6°, bipolar, samarium cobalt rotor. Holding torque 7.5 oz-in @ 0.5 A, 26Ω
ITM-26.....$20

d) 12.8 Ω version of above.
ITM-12.....$25

Also available 26 page pamphlet "Introduction to Stepper Motor Technology"
ITB-01.....$5

Call or write for additional information

Intrinsic Technologies, Inc.
P.O. Box 700220, San Jose, CA 95170
408/245-6320



Circle 7

trusion detection is addressed through the use of five passive true-infrared body heat detectors, four passive optical motion detectors, ultrasonic motion detectors, vibration monitoring, and discriminatory hearing. Approximately 256 internal circuitry checkpoints on ROBART II constantly monitor circuit performance, system configuration, operator-controlled switch options, cable connections, and interface card integrity. Speech output is generated by the self diagnostics to advise of any difficulties.

While ROBART II is by no means complete at this point, most of the hardware has been installed and tested. A considerable amount of software has been written for the dedicated controllers in the lower level, and for the Scheduler. The communication protocols for information transfer up and down the hierarchy have been developed and implemented, and the entire system is currently operational and capable of limited autonomous behavior. With the addition of the stereo vision system and remaining near-infrared proximity detectors for collision avoidance, and the enhancement of the existing software packages for each of the dedicated controllers, ROBART II should prove to be an unequalled sensor testbed ideally suited for further research into the areas of collision avoidance, domain mapping, and autonomous navigation. The robot is quite often on loan to the Robotics Research and Development Lab at the Naval Surface Weapons Center in White Oaks, Maryland, where it is used for sensor evaluation and as a research tool by the Navy.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

74	84	94
Excellent	Good	Fair

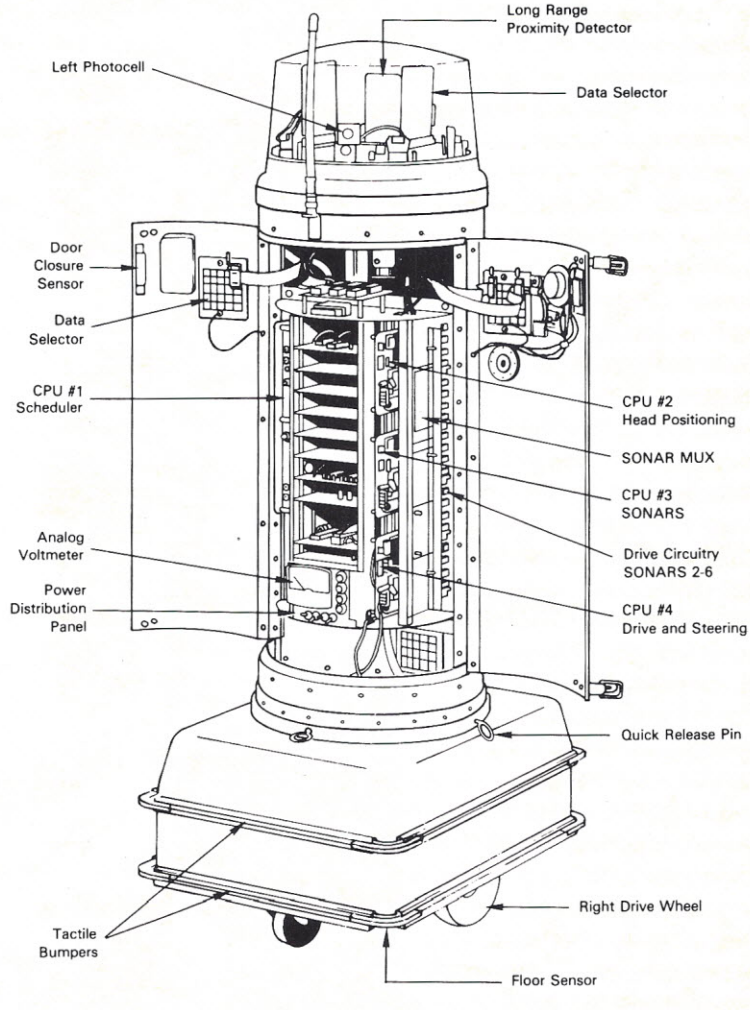
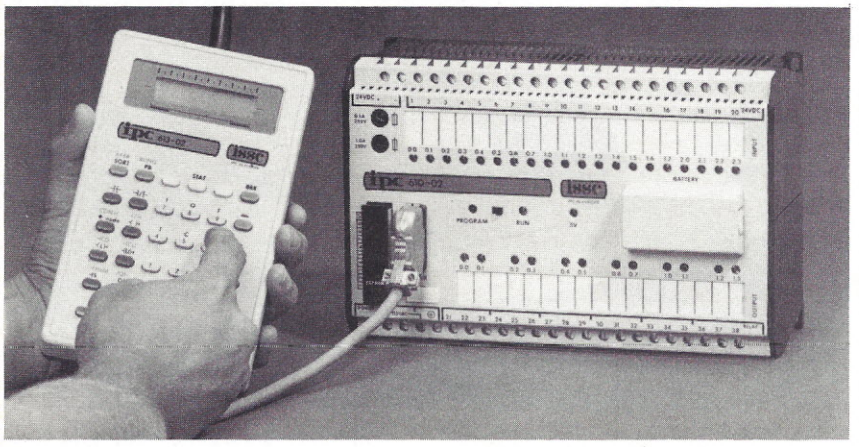


Figure 3. The right rear view shows the location of the SONAR multiplexer and individual driver cards. CPUs 2, 3, and 4 are single-board MMC-02 systems made by R.J. Brachman and Associates, each containing two 6522 Versatile Interface Adapters (VIAs) with 8 Kbytes of RAM/EPROM on board.

New Products



Micro Programmable Controller

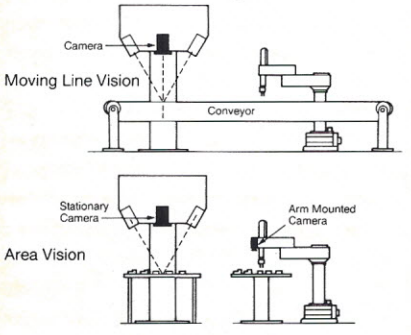
ISSC has introduced the IPC 610 Micro Programmable Controller for applications such as individual control of small machines or processes requiring timing and counting functions. A hand-held programming unit, an optional plug-in memory module, and an input simulator complete the IPC 610 Micro PC line.

The controllers are offered in two models, one with 10 inputs and 6 outputs and the other with 20 inputs and 12 outputs. Both are available in 115/120 VAC or 220/240 VAC versions. The 610, which measures 6 in. X 10 in. X 4 in., fits into many areas that might typically be considered too small.

The IPC 613 hand-held loader features menu-oriented ladder diagram programming and extensive user prompting. Each controller has eight timers and eight counters, all internal. The CMOS RAM PC memory contents are retained by battery backup when the power is off. An optional plug-in EEPROM module is also available for permanent program storage.

For more information, contact: Larry Worth, ISSC, A Honeywell Division, 435 West Philadelphia St., York, PA 17404, telephone (717) 848-1151. Circle 40

Robot Vision System

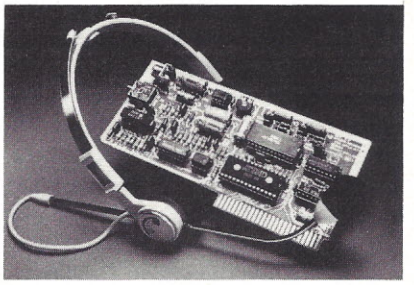


Adept Technology has developed a vision system to accompany its direct-drive robot system, the AdeptOne. The new AdeptVision was designed to address the part-acquisition problem; in the past, robots could pick up parts only if they were precisely positioned, which meant the robot workplace had to be structured to accommodate the robot. That process could cost several times the price of the robot.

AdeptVision is state-of-the-art, the company says, because it recognizes parts either stationary or on moving conveyors and then communicates the information to the AdeptOne. A new approach to the software algorithms allows AdeptVision to identify parts even if they touch each other or overlap. The vision system is completely integrated with the robot and operates out of the same controller, eliminating interface problems and reducing cost.

Teaching part recognition requires about 10 minutes per part and is carried out using the same manual control pendant that controls the robots. The conveyor version of AdeptVision can track up to 12 inches per second. Both the conveyor and the area versions can process four touching or moderately overlapping complex parts per second and handle up to eight simpler part configurations per second.

For more information, contact: Adept Technology, Inc., 1212 Bordeaux Dr., Sunnyvale, CA 94089, telephone (408) 747-0111. Circle 41



Micromint LIS'NER 1000

Micromint's new speech recognition system, featuring the SP1000 linear predictive coding (LPC) voice recognition chip from General Instruments, is both a voice recognition and voice synthesizer board for the Apple II and Commodore 64 computers. It can also be used with other 6502-based systems and is designed for speaker-dependent unconnected speech applications. LIS'NER 1000 functions as a parallel voice-entry device to the keyboard and is transparent to the operation of the computer. When it hears a word it recognizes, LIS'NER 1000 sends a preprogrammed sequence of characters to the keyboard input handler as if the word had been typed. DOS words, keyboard commands, and numbers can be spoken rather than typed.

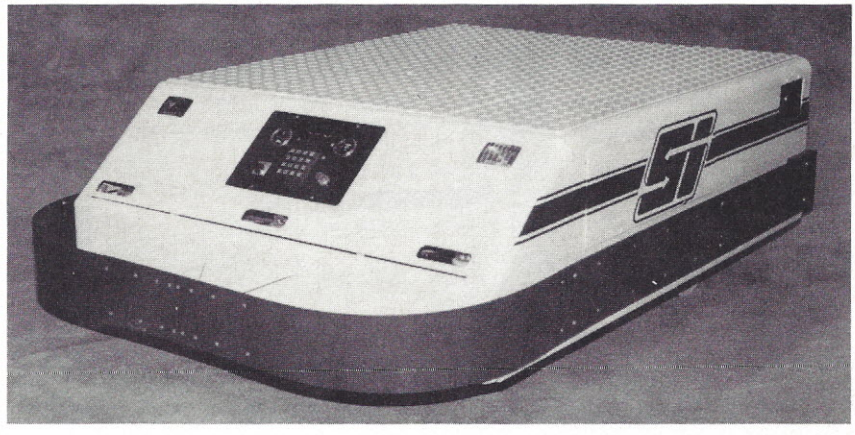
In addition to speech recognition, LIS'NER 1000 is capable of LPC speech output from a precoded word dictionary. When combined with the Apple II, it optionally accommodates an SSI 263 phonetic speech synthesizer chip with text-to-speech algorithm, facilitating true hands-off speech I/O. LIS'NER 1000 analyzes the voice input in real time by means of techniques that operate directly on the incoming data stream. Each word is condensed and stored as a unique template to which "heard" words are compared.

The recognition algorithm, which is contained in the host microcomputer's software, can be upgraded without hardware redesign. Neither extensive buffering nor large amounts of processing power are required. LIS'NER 1000 has an unlimited recognition vocabulary. Sixty-four words are recognizable at any one time, and the vocabulary fits into 8 Kbytes.

For more information, contact: Micromint, Inc., 25 Terrace Dr., Vernon, CT 06066, telephone (203) 871-6170. Circle 42

New Products

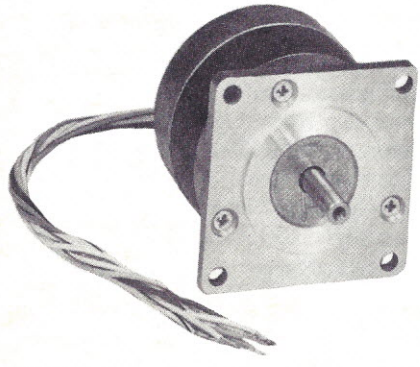
The SIdewinder



SI Handling Systems has entered the automatic guided vehicle (AGV) systems market with the addition of the SIdewinder Unit Load Carrier to its product line. The SIdewinder, a driverless, programmable, horizontal transport vehicle designed to carry loads up to 6000 lbs., interfaces with manual or automatic work stations or other material handling equipment. The battery-powered vehicle is programmed to follow in-the-floor or above-the-floor paths and to provide versatile work station interfacing along that route.

The SI Controller directs the AGV's system, providing efficient real-time control functions required by automated warehouse and factory automation systems. Functions include vehicle path optimization, automatic station selection, host computer communications, system performance reports, and interfacing with peripheral devices.

For more information, contact: SI Handling Systems, Inc., Kesslersville Rd., Easton, PA 18042, telephone (215) 252-7321. Circle 43

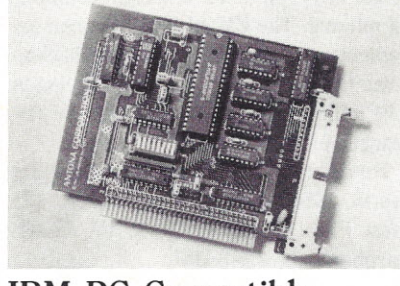


High-Accuracy Stepping Motors

Superior Electric is offering a new series of stepping motors the company describes as combining unique design features and advanced manufacturing techniques to achieve high performance and low cost. Step accuracy is guaranteed to be ±3 percent maximum and is typically ±1.3 percent. Step angle is 1.8 degrees; length is 1½ inches. The motor can withstand over five times rated current with no demagnetization.

The motors have ABEC-1 shaft bearings and 8-lead construction. They can be customized with such features as special windings, modified shafts, special lead lengths and connectors, timing pulleys, and gears.

For more information, contact: Frank A. Leachman, Superior Electric Co., 383 Middle St., Bristol, CT 06010, telephone (203) 582-9561. Circle 44

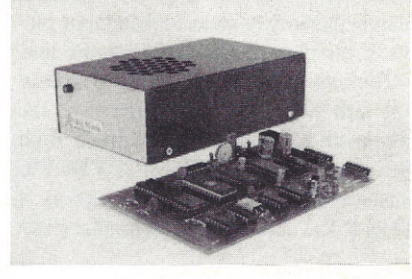


IBM PC Compatible I/O Card

Providing three 8-bit buffered TTL I/O channels, Antona's ANC-1055 occupies a short card slot in the IBM PC, XT, or AT computer. Programmable interrupt circuitry is provided to monitor four of the 24 channels to generate a user-selectable, software-enabled interrupt to the IBM PC. Three separate modes of operation, all under software control, allow bidirectional, dedicated, or strobed I/O operation.

Additionally, the ANC-1055 card is directly pin-connection compatible with the Opto 22, Crydom, and Gordos lines of modular relay boards, providing an industrial quality interface for control and monitoring applications. Programming can be performed in assembly language or by using English-like INP/OUT commands in MS-DOS BASIC.

For more information, contact: Bob Mikkelson, Antona Corp., 2100 South Sawtelle Blvd., Suite 205, West Los Angeles, CA 90025, telephone (213) 473-8995. Circle 45



The BIG MOUTH

AstroTronics has developed a voice synthesizer that can break words into syllables, syllables into phonemes, and even sing for you. The BIG MOUTH is described as a true speech synthesizer that can convert ASCII text strings into speech and say all the numbers and letters. Information can also be embedded to give full control over these speech parameters: vocal track frequency, rate, inflection, pitch, duration, amplitude, and articulation for all 64 phonemes, the discrete sounds that make up a word.

The BIG MOUTH can be interfaced with any computer, the company says, and should find applications in robotics, automatic test equipment, darkroom equipment, speech labs, and as an audio prompt in computing systems.

For more information, contact: Jon vanGelder, President, AstroTronics, 1137 Topaz St., Corona, CA 91720, telephone (714) 734-6006. Circle 46

New Products

Literature and Brochures

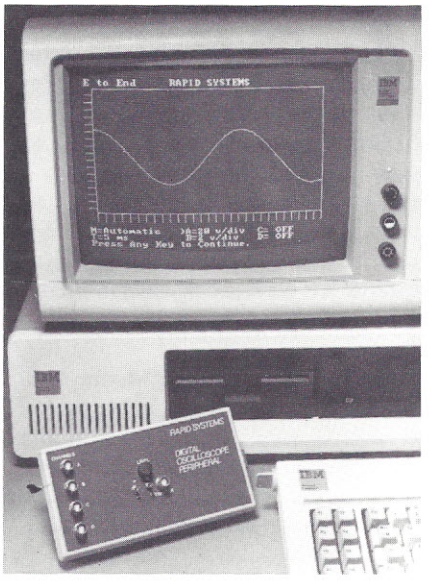
A free, 152-page full-line power supply catalog is being offered by Lambda Electronics. According to the company, the catalog's 700 entries comprise the world's largest selection of such items as switching and linear supplies, OEM switching and linear supplies, and new DC/DC supplies. Also shown are standard assemblies for custom requirements and all types of laboratory, test equipment, and system power supplies. For more information, contact: Lambda Electronics, 515 Broad Hollow Rd., Melville, NY 11747. Circle 47

A new guide to computer-aided design and computer-aided manufacturing systems is available from R.R. Bowker. *Robotics, CAD/CAM Market Place 1985* contains over 6000 listings of reference materials, products, on-line databases, organizations, etc. For more information, contact: Customer Service, R.R. Bowker Co., PO Box 1807, Ann Arbor, MI 48106, telephone (800) 521-8110. Circle 48

The Microelectronics Division of NCR has published a specifications brochure on its NCR/32 development system, a high-performance Multibus-compatible tool designed to evaluate the NCR/32 chipset and generate external microcode for the user's particular system application. For more information, contact: NCR Microelectronics Division, 1635 Aeroplaza Dr., VLSI Processor Products, MS 6300, Colorado Springs, CO 80916, telephone (303) 596-5612 or (800) 525-2252. Circle 49

Digital Oscilloscope Peripheral

Rapid Systems has released a 4-channel digital oscilloscope for use with IBM, Apple, and Commodore personal computers. The peripheral plugs into the PC, the supplied disk is slipped in, and the PC becomes a digital oscilloscope. It has a 2-MHz sampling rate, 500-KHz analog band width, and diode protection on all inputs. The color-enchanced graphics display uses up to 138 X 288 pixels for data and four lines of text for displaying values of the scope's parameters.



The menu-driven operation provides keyboard control of gain parameters for the four channels, time base values, number of channels, and trigger mode. Also, all the post-processing capabilities of the PC are available: to store and retrieve wave forms from disk, to analyze and process the information, and to compute and word process.

For more information, contact: Bo Ray, Rapid Systems, 5415 136th Place S.E., Bellevue, WA 98006, telephone (206) 641-2141. Circle 50

Classifieds

Millers Custom Gear Cutting and Machining, Write to: David G. Miller, 23½ E State St., Alliance, OH 44601.

Radio-Controlled Robot Tank Plans. Use your home computer to program the tank's path. Optical interface needs no wires into your computer. All parts from Radio Shack. Complete schematics, instructions, and software—$14.95. **CYNZAC ENGINEERING,** 6117 Calle Arena, Camarillo, CA 93010.

AUTOMATE AFFORDABLY WITH spectraLIGHT™

FEATURES:

- Integrates with a personal computer (Apple IIe, II+, IBM PC)*
- Disk based menu driven software provides:
  - Quick development of NC programs
  - Graphic part verification
  - Manual and automatic lathe operation
- Turns steel, aluminum, brass and plastic
- Improves productivity for small production runs
- Conventional CNC G and M codes
- Cost-effective for training new CNC operators

*Apple is a trademark of Apple Computer Inc. IBM is a trademark of International Business Machines Corp.

INDUSTRIAL GRADE AUTOMATION

ONLY $2995.

LIGHT MACHINES CORPORATION

669 East Industrial Drive, Manchester, NH 03103
(603) 625-8600

LATHE SPECIFICATIONS:

- 3.5" swing over bed
- 8" between centers
- ±.0005" positioning repeatability
- 200 to 2000 RPM spindle speed
- 115V power requirement
- Ball bearing spindle
- Adjustable gib slides

Call Toll Free 1-800-221-2763

New Products

Stepping-Servo Controller Chip

A stand-alone, single-chip DC motor controller designed to replace stepper motor control systems has been introduced by Galil Motion Control. The GL-1200 accepts input commands in the same simple pulse train format that moves traditional stepper motors, but, according to the manufacturer, it provides precise closed-loop control. It is packaged in a 20-pin DIP for quick replacement in systems currently using steppers.

GL-1200, which does not require tachometer feedback, uses only an incremental encoder to stabilize the servo loop with specialized compensation circuitry. Applications for the chip include plotters, tape drives, printers, robotics, material handlers, and factory automation equipment.

For more information, contact: Lisa Wade, Galil Motion Control, 1916-C Old Middlefield Way, Mountain View, CA 94043, telephone (415) 964-6494. Circle 51

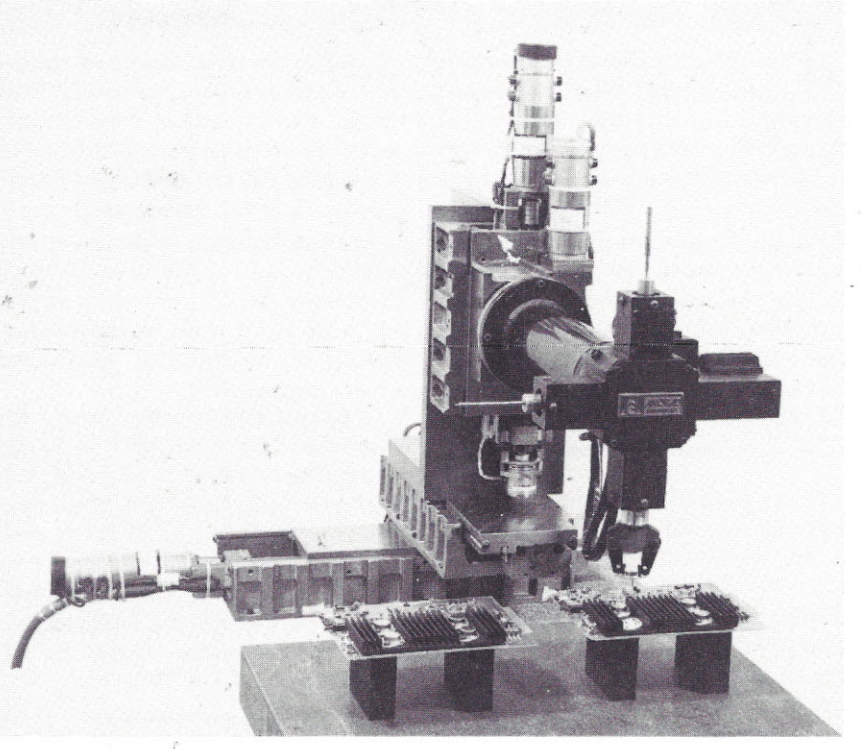
Speech Recognition System

The VET-232 SD voice-entry terminal from Scott Instruments Corp. is a continuous speech recognition system with a 200-word vocabulary. The user may speak in sentences or phrases; words not in the terminal's vocabulary are simply ignored. Prototype terminals now available also offer optional speaker-independent speech recognition and speech response that reacts to the words "yes" and "no" as well as the digits 0 through 9. For an additional charge, the company will prepare custom vocabularies. The voice response option provides high-quality playback of digitized speech and can be used to prompt operators, confirm entries, and report results.

The VET-232 SD includes features to support voice store-and-forward. A telephone management system can be added as enhancement. The terminal comes with 128 K of RAM, which is expandable to 256 K, a microphone, and a speaker. It communicates with the host system via a standard RS-232 link.

For more information, contact: Charles R. Kee, Jr., President, Scott Instruments Corp., 1111 Willow Springs Dr., Denton, TX 76205, telephone (817) 387-9514.

Circle 52



Automatic Calibration and Tuning Robot

The Anorobot, new from Anorad, is described as an automatic calibration and assembly robot that integrates high-accuracy positioning technology with the robotic senses of vision and touch for the purpose of assembling, adjusting, and tuning electronic PCB components.

The system combines high-accuracy X-Y-Z linear tables and rotary stages for positioning the robot. One rotary stage controls the four-position work turret; another controls the tool rotation. The turret allows selection of adjusting tools, vision camera, or end effectors. The system includes optical positioning sensors or automavision camera for accurate work piece location. Touch sensors are used for the treatment of delicate objects. Electrical feedback signals from automatic testing apparatus are used by the Anomatic programmable microprocessor controller to tune, calibrate, or adjust components.

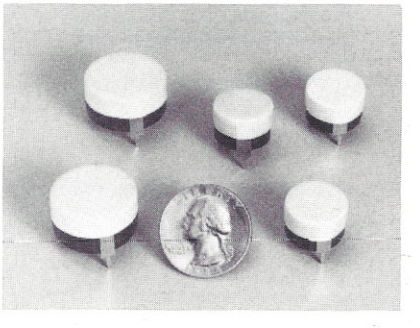
For more information, contact: Anorad Corp., 110 Oser Ave., Hauppauge, NY 11788, telephone (516) 231-1990.

Circle 53

Mini Button and Micro Pill

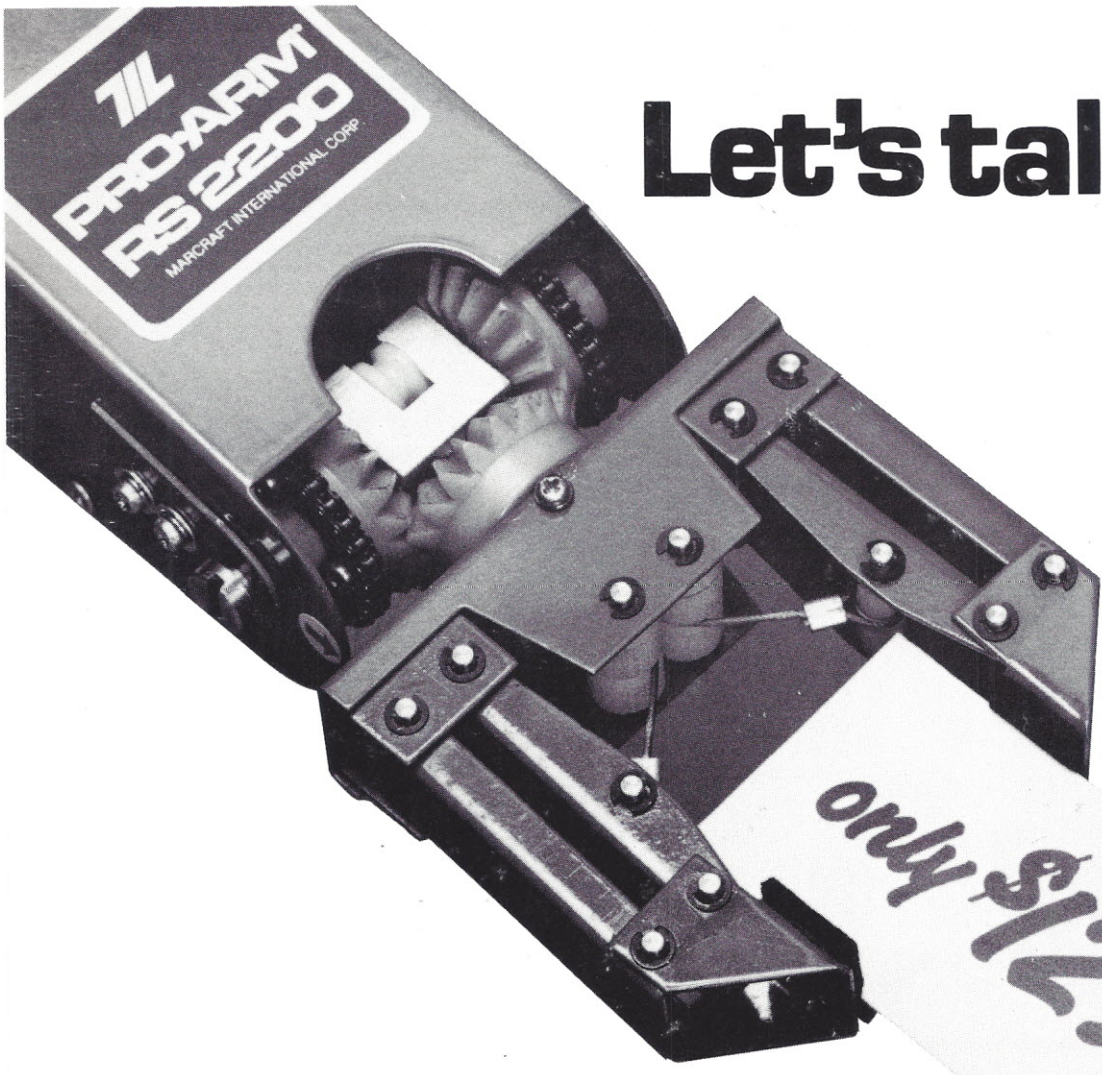
Plainview Electronics has announced two new rechargeable NiCad, low self-discharge memory backup batteries. The Mini Button is 3.6 V at 110 mAh. It is 0.9 in. in diameter and 0.5 in. high. The Micro Pill, with a diameter of 0.65 in. and a height of 0.435 in., offers 3.6 V at 35 mAh. Both are wave solderable, PC mount batteries. Pins are on standard grid format. Both batteries are available in other voltages, with accompanying height increases.

For more information, contact: Plainview Electronics Corp., 28 Cain Dr., Plainview, NY 11803, telephone (516) 249-6677.



Circle 54

Let's talk cost



only $1295

EDUCATIONAL • COMPLETE • EASY-TO-USE • RUGGED

AFFORDABLE ROBOT TRAINING ARM

PRO-ARM®

MARCRAFT ROBOT TRAINING ARM

A complete robot training program for only $1295. Complex 5 axis operations in a computer-controlled stand alone unit that simulates large industrial robots. Oh, you can spend more, but you won't find a more cost effective way to teach robotics.

Why wait? At only $1295 per robot work station, you can afford to add robotics to your curriculum now! PRO-ARM has the reliability and built-in quality that has made Marcraft a leader in the educational market.

Marcraft International Corp.
100 N. Morain St., Kennewick, WA 99336

PRO-ARM MODEL RS 2200

- Complete education courseware.
- Ready to use out-of-the-box. All parts and cables included.
- Exclusive Marcraft DEMO disk and teach program for IBM-PC© and Apple IIe©.
- Easy operation makes it simple to teach robotic theory and application.
- Rugged, built to withstand daily student use.
- Operates from the parallel printer port of any computer and includes a parallel interface card for the Apple IIe©.
- Features internal RAM memory and two built-in self-test circuits. Includes circuitry for use with external interlock switches.
- Operates in 5 axis plus gripper and can lift up to one pound.
- One year guarantee on stepping motors.

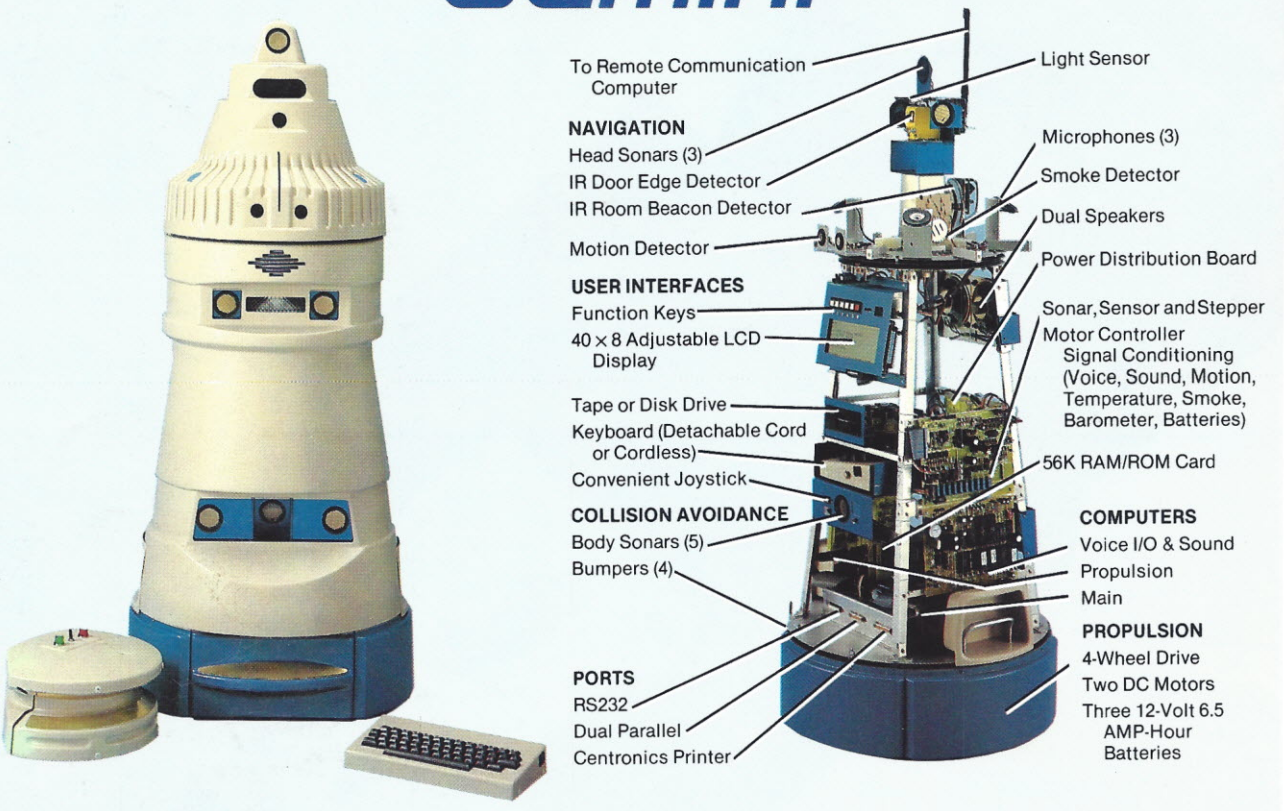
IBM-PC© IBM Corp. Apple IIe© Apple Computer, Inc.

FOR IMMEDIATE ACTION CALL TOLL-FREE 800 441-6006 (WA residents) 509 783-7359

Circle 24

introducing the world's first autonomous personal robot . . .

GEMINI™



Your new robot will find its way around your home and office, perform preassigned tasks, charge its own batteries, talk to you and obey your spoken commands.

This remarkable life-sized robot is controlled by three on-board computers, an unprecedented 108K bytes of built-in software and a sophisticated array of electronic sensors all integrated together to give it life-imitating artificial intelligence.

You'll know the moment you power up GEMINI that you have a real robot. One that performs a self check of its hardware while verbally and visually informing you of the results. One that will keep itself alive while always monitoring its multiple inputs for your commands.

Ready made, easy-to-use software will allow you to demonstrate most functions of the robot with single keystrokes. Missions for the robot to accomplish at future times can be assigned by anyone. No programming experience required. Important missions, too, such as periodic reminders, wake-up calls, storytelling for the kids, remote control of appliances and more.

An enhanced floating-point BASIC language will give you complete control of the robot. Commands like SPEAK, GOHOME, MOVETO, RANGE, etc., provide you with a means to develop complex programs, fast. Machine language level programs provide you with many debugging tools that you would expect to find on a real robot.

A high-level voice command language provides voice access for up to three users. And the voice I/O and sound computer can store up to 256 words or phrases, and dynamically update these as you converse with the robot. Highly accurate text-to-speech software and music programs with vocals are built-in.

GEMINI is ready for you now. Buy assembled or in modular, learn-as-you-go form. Either way, don't miss out on the chance to participate in the exciting new world of machine intelligence.

ARCTEC SYSTEMS™ is a member of the ARCTEC GROUP, INC., United States and Canada.

arctec systems™

9104 Red Branch Road • Columbia, MD 21045
(301) 730-1237
CA (619) 746-5511 • Canada (613) 592-2830

☐ Please send details on GEMINI.
☐ Please send dealer information.
☐ Interested in Club Demonstration.

Mail to: **ARCTEC SYSTEMS, INC.**
9104 Red Branch Road
Columbia, MD 21045

Name_____

Address_____

City_____

State_____ Zip_____ Pnone_____

Circle 3